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PUBLIC VERSION

**Confidential Business Information
Deleted from Post-Hearing Brief at
Pages 4 – 6, 8 – 13;
Appendices at Pages A-2, B-2, B-3,
B-8, B-10, E-2, E-3, E-4, and F-4;
And Exhibit 2.**

November 28, 2017

Via Electronic Filing and Hand Delivery

The Honorable Lisa R. Barton
Secretary
U.S. International Trade Commission
500 E Street, S.W., Room 112A
Washington, D.C. 20436

Re: Carbon and Certain Alloy Steel Wire Rod from Belarus, Italy, Korea, Russia, South Africa, Spain, Turkey, Ukraine, United Arab Emirates, and the United Kingdom Inv. No(s). 701-TA-573-574 and 731-TA-1349-1358 (Final): Post-Hearing Brief of British Steel Ltd.

Dear Secretary Barton:

On behalf of British Steel Ltd. ("British Steel"), we hereby file in the above-captioned proceeding the public version of British Steel Post-Hearing Brief in accordance with 19 C.F.R. § 201.8.

Steptoe
STEPTOE & JOHNSON LLP

In accordance with 19 C.F.R. § 201.6, British Steel requests that confidential treatment be accorded to the factual information contained within brackets in this submission. The bracketed information consists of business proprietary information obtained from the petition, questionnaire responses, and other business proprietary information released under Administrative Protective Order in this proceeding which is not publicly available. The proprietary business information so designated concerns and/or relates to British Steel and the other companies submitting the information and the disclosure of this information would cause substantial harm to the competitive position of the companies submitting that information.

This submission has been served on counsel pursuant to the attached certificate of service. Please do not hesitate to contact the undersigned if you have any questions regarding this submission.

Respectfully submitted,

Thomas J. Trendl
Richard O. Cunningham
Joel D. Kaufman

Counsel for British Steel Ltd.

CERTIFICATION OF COUNSEL

I, Thomas J. Trendl, of Steptoe & Johnson LLP, counsel to British Steel Limited, hereby certify that (1) I have read the attached submission of Post-Hearing Brief pursuant to the U.S. International Trade Commission's Investigation of Carbon and Certain Alloy Steel Wire Rod from Belarus, Italy, Korea, Russia, South Africa, Spain, Turkey, Ukraine, United Arab Emirates, and United Kingdom, Inv. Nos. 701-TA-573-574 and 731-TA-1349-1358 (Final) on November 27, 2017; and (2) the information contained in this submission is, to the best of my knowledge, accurate and complete.

DATED: 11/27/17

Thomas J. Trendl

Subscribed and sworn before me this 27th day of November, 2017

BRENDA H. ALMAZAN NOTARY PUBLIC EXP. 5-31-2018 DISTRICT OF COLUMBIA

Notary Public

My Commission expires: 5/31/18

BRENDA H. ALMAZAN
NOTARY PUBLIC DISTRICT OF COLUMBIA
My Commission Expires May 31, 2018

CERTIFICATE OF SERVICE

Carbon and Certain Alloy Steel Wire Rod from Belarus, Italy, Korea, Russia, South Africa, Spain, Turkey, Ukraine, United Arab Emirates, and United Kingdom

701-TA-573-574 and 731-TA-1349-1358 (Final)

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UNITED STATES
INTERNATIONAL TRADE COMMISSION

In the Matter of: Carbon and Alloy Steel Wire Rod from Belarus, Italy, Korea, Russia, South Africa, Spain, Turkey, Ukraine, the United Arab Emirates, and the United Kingdom: Post-Hearing Brief of British Steel	)	**PUBLIC VERSION** **Inv. Nos. 701-TA-573-574 &** **701-TA-1349-1358** **(Final)**

Post-Hearing Brief of British Steel

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November 28, 2017

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I. INTRODUCTION AND SUMMARY OF ARGUMENT

This Post-hearing Brief is submitted on behalf of British Steel Limited ("British Steel"), a foreign producer and importer of subject merchandise. This submission consists of a brief, as well as several responses to Commissioner questions.

British Steel respectfully contends that the record in this investigation directs that the Commission must determine that the domestic industry is not materially injured by reason of subject imports. This conclusion is clear based on the data for the domestic industry as whole, and is unequivocal when the data from ArcelorMittal and Republic are properly removed from the domestic industry, as the Commission has done in previous investigations.

For the reasons set forth below, 1080+ TC/TB, as defined, should be found to be a separate like product, for which a separate injury analysis should be conducted and a negative injury determination made. In this regard, British Steel concurs with the arguments made by the AWPA, KISWIRE and POSCO. Additionally, the Commission must recalculate negligibility separately based on the respective like products.

Due to extremely low level of imports from the U.K., the tiny 1% share of domestic consumption accounted for by U.K. imports, the fact that U.K. imports *decreased* from 2016 to 2017, the Commission must make a negative critical circumstances determination with respect to the U.K.

Finally, should the Commission consider threat of material injury, all possible factors establish that imports from the U.K. do not threaten to cause material injury.

II. THE DOMESTIC INDUSTRY IS NOT MATERIALLY INJURED BY REASON OF SUBJECT IMPORTS

The record in this proceeding demonstrates clearly that the domestic wire industry that brought this case has suffered no material injury caused by subject imports. The petitioners depend entirely on (a) including in their volume and market share analyses the effects of two plant closures that were not caused by imports, and (b) demanding that the Commission not apply here the analyses that it has applied in the past to every major issue in this proceeding – exclusion from volume analysis of plant closures not caused by subject imports, volume and market share increase taken from other imports rather than from domestic producers, and recognition of the effects on rod prices of declining raw material price, declining COGS and declining wire rod consumption.

A. Subject Imports Have Not Taken Volume or Market Share from the Domestic Wire Rod Industry

The undisputed facts on this record make two things clear:

- Apart from the closure of Arcelor Mittal's Georgetown, South Carolina plant and Republic's Lorain, Ohio plant, domestic firms' shipments and market share over the POI were not reduced by subject imports but instead increased significantly.
- The increase in volume of subject imports came, not at the expense of the U.S. industry, but at the expense of non-subject (particularly Chinese) imports.

It is important to recognize that petitioners do not dispute these facts. Instead, they try to explain them away by two insupportable arguments:

First, they argue that the closures of the two plants were caused by subject imports. That argument is simply wrong on the facts and is "supported" exclusively by the domestic companies' self-serving statements that do not in fact blame subject imports.

Second, they argue that the Commission should ignore the fact that subject imports' increase came at the expense of declining non-subject imports and that U.S. producers were entitled to capture the business created by China's exit from the market. That argument is flatly inconsistent with past Commission precedent, makes no economic sense and – most startlingly –

is simply wrong on the facts. Domestic producers in fact captured a larger share of the volume left by China's exit than the petitioners could have expected to capture, given their 2014 market share. The data from purchasers on their "shifts" of purchases to lower-priced subject imports further confirm this analysis.

1. The Volume Declines of Arcelor Mittal and Republic Cannot Be Included in an Analysis of the Volume or Market Share Effects of Subject Imports

There is no credible argument that either Arcelor Mittal's Georgetown, South Carolina mill or Republic's Lorain, Ohio mill would have remained open but for problems caused by subject imports. Even self-serving references to imports by the two companies do not state that subject wire rod imports caused the closures. Rather, each plant closed because of factors totally unrelated to subject imports:

- The Georgetown mill relied on DRI imported through the Port of Georgetown. When the silting of that port made its use for DRI imports impossible, the alternative of using other ports and then barging the DRI to Georgetown was uneconomic. When the State and Federal Governments refused to spend the $70 million needed to dredge the harbor, the mill was forced to close. Since unfairly traded imports declined substantially in 2015, any import impact on the Georgetown plant was due to the earlier surge in Chinese imports.
- Republic's Lorain mill was a bar mill. Production of a product classified as wire rod was a tiny portion of the plant's business. The bar operations were impacted by the severe 2015 collapse of demand for oil country steel, affecting the Lorain mill most severely when its principal customer, the adjacent U.S. Steel Lorain Tubular Operation, was shut. Bar market problems caused the Republic closure. To the extent imports played any role, they were bar imports.

The closures of these plants are discussed in detail in the response to the questions of Commissioners Johanson[1], Broadbent,[2] and Schmidtlein.[3] The issue is one of fact: Why did the plants close? The Commission's precedents on these points are clear, as discussed in the answer to a Commissioner by Commissioner Schmidtlein.[4] The answers here are equally clear.

Exclusion of those two plant closures from the analysis of volume or market share lost to subject imports during the POI yields results that are crystal clear:[5]

	2014-2016 Changes	
	Volume	Market Share
U.S. industry without Arcelor Mittal	[	]
U.S. industry without Republic	[	]
U.S. industry without Arcelor Mittal & Republic	[	]

Note in particular that, excluding either Republic or Arcelor Mittal, the U.S. industry is shown to have experienced at most a *de minimis* decline in shipments and no loss of market share.

2. The 2014-2016 Increase in Subject Imports Came at the Expense of Non-Subject Imports

The Commission has consistently found no adverse volume effects where the increase in subject imports has come at the expense of non-subject imports. Here that is indisputably the case. The [ ] ton increase in subject imports from 2014 to 2016 was substantially less

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[1] Hearing Transcript, *Carbon and Alloy Steel Wire Rod from Belarus, Italy, the Republic of Korea, the Russian Federation, the Republic of South Africa, Spain, Turkey, Ukraine, the United Arab Emirates, and the United Kingdom*, Inv. Nos. 701-TA-573-574 and 731-TA- 1349-1358 (Final) (Nov. 16, 2017) ("Tr.") at 81 and 111 (Johanson).
[2] Tr. at 100-101 (Broadbent).
[3] Tr. at 180, 182 and 185 (Schmidtlein).
[4] Tr. at 181-82 (Schmidtlein).
[5] Pre-hearing Staff Report at IV-29, Table IV-14, adjusted for commercial shipments by Arcelor Mittal and Republic, from responses to question II-7 in Arcelor Mittal final investigation questionnaire report and Republic preliminary investigation questionnaire report. The full computation is shown in the responses to Commissioners' questions.

than the [ ] ton decline in Chinese imports,[6] while the U.S. industry shipments (excluding Arcelor Mittal and Republic) increased.

Petitioners seek to avoid this fatal problem by asking the Commission to reject its clear precedent that an increase in subject imports does not constitute injury to domestic producers when it comes at the expense of non-subject imports, even where the decline in non-subject imports is caused by imposition of Title VII duties. Whatever the reason for that decline, the fact remains that, during the POI, the effect of the subject import increase was not on domestic producers. This issue is discussed in more detail in response to questions by Commissioners Broadbent, Johanson and Williamson.[7]

Equally important, petitioners' argument is wrong on the facts. Subject imports did not deprive the petitioners of the volume they could reasonably have expected to obtain as Chinese imports left the market. At the start of the POI in 2014, petitioners' shipments (not including Arcelor Mittal and Republic) share of the merchant market was [ ] percent. If the petitioners had captured that share of the departed Chinese volume, their shipments would have risen by only [ ] tons, but in fact they increased by [ ] tons or [ ] percent of the departed Chinese volume.[8]

As discussed in the response to a question posed by Commissioner Broadbent,[9] the purchasers' responses to the Commission's shifting based on lower price question provides further confirmation that little if any gains by subject imports came at the expense of domestic producers.

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[6] Pre-Hearing Staff Report at IV-4, Table IV-2. The subject import increase was also less than the 279,771 ton increase in all non-subject imports.
[7] Tr. at 66 (Broadbent), 193 (Johanson) and 236 (Williamson).
[8] Pre-Hearing Staff Report at IV-25, Table IV-12, adjusted by data from responses of Arcelor-Mittal and Republic to Question II-9, U.S. Producers' Questionnaire.
[9] Tr. at 208 (Broadbent).

B. Subject Imports Have Caused No Adverse Price Effects

Petitioners have chosen to ignore almost entirely the analysis that the Commission has consistently applied in recent steel cases to determine whether subject imports have caused the suppression or depression of prices.

As to price suppression, the Commission has examined whether, in a period of declining apparent consumption and falling cost of goods sold (COGS), domestic producers would have been able to put price increases into effect. In the preliminary determination here, the Commission found that increases in wire rod prices would have been unlikely because of the steady and substantial fall in average COGS at a time of declining apparent domestic consumption. That determination remains valid, as the Pre-Hearing Staff Report shows COGS per ton falling precipitously, from [ ],[10] and consumption declining by [ ] percent.[11]

Cost declines – and particularly the steep fall in the highly visible scrap steel price – also fully explain the decline in wire rod costs and negate any possible contention that subject imports caused price depression. This issue is discussed in detail in response to the questions of Commissioners Schmidtlein,[12] Johanson[13] and Williamson,[14] but the evidence may be summarized as follows:

- Trends in steel scrap prices are closely monitored by purchasers, and are used by them to press producers to lower rod prices.

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[10] Pre-Hearing Staff Report at VI-9, Table VI-3.
[11] *Id.* at IV-24. See also discussion in response to question of Commissioner Broadbent.
[12] Tr. at 75.
[13] Tr. at 112, 114, 198-199 (Johanson).
[14] Tr. at 202.

- Here, during the 2014-2015 period of falling wire rod prices, scrap steel prices fell much more steeply, pulling wire rod prices down until early 2016.
- The trend of scrap steel prices coincides precisely with the trend in rod prices, pulling them down through 2015, then turning upward at year-end and leading rod prices back up. Petitioners acknowledged this.[15] The correlation with the six pricing products is strikingly clear. There is no such correlation with unfairly traded imports, which declined in volume and market share in 2015. Scrap steel and rod prices both turned up more than a year before the filing of these cases, and have continued to rise despite increases in the volume of unfairly traded imports. As petitioners' counsel admitted, these cases were not filed in 2015 because unfairly traded imports "hadn't surged yet."[16]
- The Commission's preliminary determination observation, that rod prices decline while subject import underselling resulted in lost market share for the domestic industry, is no longer valid, since the domestic producers, and from Arcelor Mittal and Republic gained market share.

In short, the record here is clear that subject imports caused neither price depression nor price suppression.

III. THERE IS NO REASONABLE INDICATION THAT IMPORTS OF CARBON AND ALLOY STEEL WIRE ROD FROM THE UNITED KINGDOM THREATEN TO CAUSE MATERIAL INJURY TO THE U.S. INDUSTRY

Just as the foregoing discussion demonstrates that there is no reasonable indication that subject imports cause injury to the domestic wire rod industry, so too does the record make abundantly clear there is no reasonable indication that they threaten to cause material injury.

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[15] Tr. at 80 (Rosenthal and Nystrom).
[16] Tr. at 63 (Rosenthal).

Section 771(7)(F) of the Tariff Act directs the Commission to determine whether an industry in the United States is threatened with material injury by reason of the subject imports by analyzing whether "further dumped or subsidized imports are imminent and whether material injury by reason of imports would occur unless an order is issued."[17]

Cumulation is not mandatory in the threat of material injury analysis. Under the Act, the Commission "may" cumulatively assess the volume and price effects of importers, "to the extent practicable."[18] Given the Commission's statutory authority to exercise discretion, the arguments presented below are made on behalf of United Kingdom alone. Furthermore, though the Commission issued foreign producers' questionnaires to two wire rod producers in the United Kingdom, British Steel accounts for [ ] percent of total wire rod exports to the United States.[19] For this reason, the threat of material injury analysis is limited to the production and export activities of British Steel.

The statute provides the Commission with nine factors that are to be used to determine whether imports threaten to cause material injury to the domestic industry.[20] The Commission is to consider these threat factors "as a whole," meaning that the existence of any one threat factor does not require an overall affirmative finding of threat.[21] Each of these factors is analyzed below.

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[17] 19 U.S.C. §1677(7)(F)(ii).
[18] 19 U.S.C. §1677(7)(H).
[19] Pre-Hearing Staff Report, Table VII-32 at VII-61.
[20] 19 U.S.C. §1677(7)(F)(i)(I)-(IX).
[21] 19 U.S.C. §1677(7)(F)(ii). *See also Certain Steel Wheels from China*, Inv. Nos. 701-TA-448 and 731-TA-1182 (Final), USITC Pub. No 4319, at 27-28 (May 2012) (finding no threat of material injury despite "the considerable size of the Chinese industry, its moderate export orientation, the reported existence of excess capacity during the period examined, some potential for product shifting, and the existence of trade measures on Chinese exports of steel wheels to India").

The Nature of the Subsidy. This factor is not applicable, as the petitioners do not seek the imposition of countervailing duties on CASWR from the United Kingdom, and allege no evidence of any countervailable subsidy with regard to the United Kingdom.[22]

Production Capacity. There are no imminent, substantial capacity increases planned in the United Kingdom that suggest the likelihood of substantial increased imports into the United States. British Steel is already producing at a [ ] and the capacity utilization rate is projected to increase even further – by [ ] percentage points – from 2016 to 2018.[23] Moreover, British Steel is examining [ ],[24] which would likely lead to an even greater [ ].[25] Nucor cites to capacity increases from 2014 to 2016,[26] but misses the fact that all questionnaire data prior to June 1st 2016 is that of Tata Steel. British Steel only formed when Greybull Capital acquired Tata Steel's shares of Longs Steel UK on June 1st 2016.[27]

In addition to this high utilization rate, British Steel only exports a miniscule share of its overall shipments to the United States. In 2017, British Steel's exports to the United States accounted for approximately only [ ]% of its total shipments – a value projected to decrease even more by 2018.[28] Not only is this rate extremely low, but over the span of the POI, the

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[22] Letter from Wiley Rein and Kelley Drye & Warren to the Honorable Lisa R. Barton and Wilbur L. Ross re: *Carbon and Alloy Steel Wire Rod from Belarus, Italy, the Republic of Korea, the Russian Federation, the Republic of South Africa, Spain, Turkey, Ukraine, United Arab Emirates, and the United Kingdom: Petitions for the Imposition of Antidumping and Countervailing Duties* (March 28, 2017) at 1 ("Petition").
[23] Pre-Hearing Staff Report, at VII-62.
[24] British Steel Foreign Producers' Questionnaire at 8.
[25] Id.
[26] Letter from Wiley Rein to the Honorable Lisa R. Barton re: *Carbon and Certain Alloy Steel Wire Rod from Belarus, Italy, Korea, Russia, South Africa, Spain, Turkey, Ukraine, United Arab Emirates, and United Kingdom: Nucor Corporation's Prehearing Brief* (Nov. 13, 2017) at 45 ("Nucor Corporation's Prehearing Brief").
[27] British Steel Foreign Producers' Questionnaire at 6.
[28] Pre-Hearing Staff Report, at Table VII-33.

significance of the U.S. market to British Steel and its predecessor company has fallen, not risen. The current U.S. market share as a percent of British Steel's total shipments has fallen nearly [ ]% over the course of the POI.[29] The relatively insignificant reliance of British Steel on sales into the U.S. market is reflected by its meager market share of total imports into the United States. During the most recent 12-month period for which data are available, shipments from the United Kingdom constituted only **2.6%** of total U.S. imports of CASWR.[30]

Taken together, British Steel's high utilization rate and low and decreasing volume of United States exports serve as incontrovertible evidence that the United Kingdom does not pose a threat of imminent material injury to the United States.

Future Volumes. There furthermore is no evidence to suggest that imports of wire rod from British Steel will increase in the imminent future. As discussed above, exports to the United States have [ ] over the POI.[31] Furthermore, the high and growing rate of capacity utilization indicate that this trend will continue and that U.S. shipments as a share of total shipments will not increase in the foreseeable future.

The combined responses to the U.S. Importers' Questionnaire on arranged imports further support this conclusion: [ ] and none thereafter. Thus, nothing in the record suggests that future import volumes are likely to increase significantly.

Future Pricing. British Steel's strategy has been to focus increasingly on selling high-quality wire rod, especially tire cord and tire bead quality rods, which command a sizeable price premium over other high carbon products. These products require exacting production methods

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[29] Pre-Hearing Staff Report, at Table VII-33.
[30] Pre-Hearing Staff Report at IV-15.
[31] Id.

and certification requirements, including use of the BOF method of production that no U.S. steel mill currently operates, in order to achieve the purity and durability levels required by global downstream manufacturers. In particular, as the tire industry becomes increasingly demanding, requiring ever higher tensile strength and higher carbon grade, British Steel seeks to [ ].

As such, British Steel aims to maximize its profits by focusing on the highest quality products and charging the highest price possible on its sales. Its market strategy has not been based on reducing prices to gain market share, and there is no reason to believe that it would do so now, particularly given the premium product mix it offers.

Inventories. British Steel held very little inventory – approximately [ ] – over the course of the POI, which is projected to decrease even further in 2017 and 2018.[32] At this low level, British Steel only maintains enough inventory to satisfy approximately [ ] of shipments. These levels are clearly too insignificant to constitute a threat to the U.S. industry.

Product Shifting. In 2017, British Steel entered into an agreement with the owners of [ ] regarding the purchase of a wire rod mill in the Netherlands that specializes in high quality wire rods.[33] This venture, in addition to British Steel's intention to expand into higher quality products in the existing UK wire rod facility, shows a concerted strategy to enter higher value products and reduce production of subject merchandise.

Agricultural Products. This factor does not apply as these investigations do not involve any agricultural products.

Impact on R&D Expenses. There is no evidence that imports from the United Kingdom have had any significant negative effects on R&D efforts undertaken by domestic producers.

[32] Pre-Hearing Staff Report, Table VI.
[33] British Steel Foreign Producers' Questionnaire, at 6.

Over the POI, R&D expenses as a share of gross profit has remained fairly steady – decreasing only [ ] from 2014 to 2017.[34]

	Calendar Year			**January to September**	
	2014	**2015**	**2016**	**2016**	**2017**
R&D Expenses	[				]
Gross profit	[				]
R&D as Percentage of Profit	[				]

Other Demonstrable Trends. The information discussed above is supports a finding that there is no threat of injury on the record in these investigations, and no other demonstrable adverse trends are present.

IV. CRITICAL CIRCUMSTANCES TO NOT EXIST WITH RESPECT TO BRITISH IMPORTS

Petitioners attempted to make a critical circumstances argument with respect to the United Kingdom in their pre-hearing brief[35] and at the hearing,[36] claiming that there was a "surge." In doing so, counsel for petitioners' did exactly what they said was unfair—using percentages rather than "real numbers.[37]" Looking at the "real numbers" collected by the Commission, British Steel notes that **imports from the U.K. amounted to just 1% of total U.S. domestic consumption—a share that DECREASED from 2016 to 2017**. On this basis alone, it is impossible for imports from the U.K. to "likely undermine seriously the remedial effect" of the order.

[34] Pre-Hearing Staff Report at VI-5 and VI-15.
[35] Nucor Corporation's Prehearing Brief at 58-64.
[36] Tr. at 38-39 (Rosenthal).
[37] Tr. at 74, lines 13-14 (Price).

Comparing imports using the same 6 month period the Department used, it is true that imports increased from [ ] short tons from October 2016 through March 2017, to [ ] short tons between April and September 2017—an increase of a miniscule [ ] tons, though British Steel notes that the latter period includes data from the 3rd quarter which petitioners themselves admit is a seasonal period of greater imports. As such, there is nothing about the volume of imports, the timing of imports, nor a rapid increase in imports from the U.K. which supports a critical circumstances finding. In fact, review of all data requires a negative critical circumstances determination with respect to the U.K.

V. 1080+ TIRE CORD AND TIRE BEAD (1080 TC/TB) IS A SEPARATE LIKE PRODUCT FOR WHICH A SEPARATE INJURY ANALYSIS AND A SEPARATE NEGLIGIBITY TEST SHOULD BE PERFORMED

British Steel has provided extensive information about the production, characteristics and uses for 1080+ TC/TB, as defined, in its Pre-hearing Brief and in its preliminary phase Post-conference Brief. British Steel also fully supports the arguments made by the AWPA, POSCO and KISWIRE on this issue. Moreover, a great deal of highly pertinent information was elicited during the hearing establishing that 1080+ TC/TB is a fundamentally different product from other standard wire rod from how it is produced, marketed and sold. The Commission heard from a number of industry witnesses—producers and users—about how much has changed since the Commission last seriously considered this issue and why 1080+ TC/TB is a product very unlike the other products subject to this investigation. The fact is that there is no basis to conclude that 1080+ TC/TB, as defined, is another wire rod product in a continuum of other wire rod products. The only factually correct and legally supportable determination is that 1080+ TC/TB is a separate like product for which a separate injury analysis should be conducted. When this injury analysis is conducted and the financial and trade data for the domestic producers of 1080 is analyzed, it is clear that there is no material injury to the domestic industry. British Steel further address questions from the Commissioners on this issue in the attachments.

With 1080+ TC/TB being found to be a separate like product, the Commission also should recalculate country-specific data for purposes of negligibility.[38]

VI. CONCLUSION

For the reasons set forth above, British Steel respectfully requests that the Commission determine that the domestic industry is not materially injured or threatened with material injury by reason of subject imports. 1080+ TC/TB, as defined, should be found to be a separate like product, for which a separate injury analysis should be conducted and a negative injury determination made. Additionally, the Commission must recalculate negligibility based on the separate like products, respectively. Regarding critical circumstances, all data and examination of the Commission's traditional factors demonstrate that the Commission must make a negative critical circumstances determination with respect to the U.K. Finally, should the Commission

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[38] *See* 19 U.S.C. §1677(24)(A)(i) (noting that negligibility should be measured for imports "corresponding to *a* domestic like product identified by the Commission," which directs the Commissioners to consider negligibility separately for each like product rather than for all imports collectively). *See also Certain Kitchen Appliance Shelving and Racks from China*, Inv. Nos. 731-TA-1154 (Final), USITC Pub. No 4098 (Aug. 2009) (where the ITC found appliance shelving and racks to be separate domestic like products and considered the negligibility of each separately); *Hydrofluorocarbon Blends and Components from China,* Inv. Nos. 731-TA-1279 (Final), USITC Pub. No. 4629 (Aug. 2016) (where the ITC found HFC blends and components to be separate domestic like products and considered the negligibility of each separately); and *Certain 4,4-Diamino-2,2-Stilbenedisulfonic Acid Chemistry from China, Germany, and India*, Inv. Nos. 701-TA-435 (Preliminary), USITC Pub. No. 3608 (July 2003) (where the concurrence viewpoint found multiple like products and analyzed the negligibility of each separately). Even where the ITC did not ultimately find a separate like product, it engaged in a hypothetical analysis of "what the negligibility ratio would be should the Commission find that black plate is a separate domestic like product" as part of its negligibility consideration. *See Cold-Rolled Steel Flat Products from Brazil, China, India, Japan, Korea, Netherlands, Russia, and the United Kingdom*, Inv. Nos. 701-TA-540 – 544 and Inv. Nos. 731-TA-1290 (Preliminary) USITC Pub. No. 4564 (Sept. 2015).

consider threat of material injury, it should do so on a country-specific basis; analysis of all factors establish that imports from the U.K. do not threaten to cause material injury.

Respectfully submitted,

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APPENDIX A

BY COMMISSIONER BROADBENT (Tr. at 63): "Well when you look at the market, when we looked at the market in 2015 and all this unfair trade was going on, why didn't you file these cases then on the 10 other countries?

Commissioner Broadbent's question and the response it elicited are central to any analysis of this case. The record makes clear that, to the extent petitioners can argue that they suffered any injury at all during the POI, that injury occurred in 2015:

From the standpoint of volume and market share, the entirety of the industry's decline – indeed, more than the entirety of these declines – occurred with the closure of Arcelor Mittal's Georgetown, SC plant. That closure occurred in 2015.

From the standpoint of price effects, the decline in wire rod prices began at the outset of 2014 and reached the lowest point at the end of 2015. Throughout 2016 and 2017, wire rod prices have been rising.

Why then was this case not brought in 2015 or, at the latest, in early 2016? Mr. Rosenthal, in answering Commissioner Broadbent's question, was quite candid that the industry did not believe that subject imports' behavior in 2015 warranted action under Title VII:

> The imports from those ten other countries hadn't surged yet, and we were hopeful that they were not going to surge.… it was only when the imports began to come in and actually surged to the levels where the Chinese were at that it began or not began, it got worse. (Tr. at 63) (Rosenthal).

This statement, seemingly in conflict with Commissioner Schmidtlein's observation (Tr. at 185) that "from '14 to '15 is the greatest increase in the subject imports of this case," is consistent with the petitioners' recognition that it is the volume of unfairly priced imports – not just subject imports – that must be considered in determining whether harm suffered by U.S. producers meets the requirements of the statute. Over and over, petitioners have emphasized that their problem is that the increase in subject imports maintained and even increased the level of unfairly priced imports that had come originally from China.

But that did not happen in 2015. As shown by the table below, the level of unfairly traded imports in fact declined significantly, as the sharp drop in Chinese imports was much larger than the increase in subject imports:[1]

	2014	2015	Change
"Unfairly" Traded Imports (China plus subject)	[		]
Percent of Apparent Domestic Consumption	[		]

Thus, the U.S. industry volume in 2015 (through the closure of Arcelor Mittal) and the 2014-15 decline in wire and prices cannot be attributed to unfairly traded imports, which declined significantly from 2014-2015. And the petitioners recognize this, as demonstrated by their decision not to bring this case until 2017, almost two years later.

But in the 2016-17 period, when petitioners express the concern that a further increase in subject imports reached a level higher than the earlier Chinese imports, the domestic industry clearly suffered neither volume nor price effects. If the Arcelor Mittal closure cannot be attributed to unfairly priced imports (which were declining significantly in 2015), the petitioners' volume and market share both <u>increased</u> significantly from the beginning of 2016 onward. Subject imports may have showed some further increase, but they did not harm domestic producers.

[1] Pre-Hearing Staff Report at IV-25, Table IV-12.

APPENDIX B

Questions Concerning the Closures of the Arcelor Mittal and Republic Steel Mills

BY COMMISSIONER JOHANSON (Tr. at 81): "Respondents take the position that factors other than subject imports explain the closure of the plant in Georgetown, South Carolina.… How do you respond to these allegations and other factors the Respondents have identified, including reports of silt buildup that prevented certain raw materials from being imported into the port near the facility and Nucor's construction of a state-of-the-art rod mill nearby."

BY COMMISSIONER BROADBENT (Tr. at 100-101): "I happened to see {101} some article that that plan{t} in Georgetown was up-river of a big silt barrier that the Corps of Engineers decided not to dredge, so they couldn't get any of their … input product."

BY COMMISSIONER SCHMIDTLEIN (Tr. at 180): "So with regard to your position that imports had nothing to do with Arcelor Mittal's decision to shut down, just so I understand, why do you think … that they cite imports as one of the reasons. Is that just – are they lying or –"

BY COMMISSIONER SCHMIDTLEIN (Tr. at 182): "So why is Libertyhouse thinking of buying them then, if the harbor presents such a problem for wire rod manufacture there? Aren't they going to have the same transportation cost issue?"

BY COMMISSIONER SCHMIDTLEIN (Tr. at 185): "{I}n January of that year {2015}, we made a determination that Chinese imports were injuring the industry, of which Arcelor Mittal was a member of at that time, and then five months later they announced they're closing. In the meantime, you know, from '14 to '15 is the greatest increase in the subject imports of this case."

BY COMMISSIONER JOHANSON (Tr. at 111): "Respondents dispute that subject imports explain the closure of the Republic's steel facility in Lorain, Ohio, pointing instead to among other matters … the idling of U.S. steal {sic} and major bar producer and the decline in oil and gas markets.… How do you all respond to these claims regarding the plaint in Lorain, Ohio?"

The Commissioners' emphasis on these two plant closures is entirely appropriate. The record shows quite clearly that only Arcelor Mittal and Republic experienced volume and market share declines during the POI. The other members of the industry, despite underselling and increases in volume by subject imports, recorded significant gains in volume and market share during the 2014-2016 period. This is shown clearly in the Pre-Hearing Staff Report, Table IV-14 at p. IV-30, adjusted by U.S. commercial shipments data from Arcelor Mittal's and Republic's responses to Question II-7 of the U.S. Producer's Questionnaire:

<u>U.S. Merchant Market Shipments</u>	<u>2014</u>	<u>2016</u>	<u>Change</u>
All U.S. Producers	[		]
Excluding Arcelor Mittal	[		]
Excluding Republic	[		]
Excluding AM and Republic	[		]
<u>U.S. Merchant Market Shares</u>			
All U.S. Producers	[		]
Excluding Arcelor Mittal	[		]
Excluding Republic	[		]
Excluding AM and Republic	[		]

These figures demonstrate that the members of the U.S. industry other than Arcelor Mittal and Republic have done well on a shipment and market share basis during the POI. Indeed, excluding <u>either</u> Republic or Arcelor Mittal from the market share calculation shows that subject imports have taken no market share from U.S. producers.

The petitioners have offered no evidence whatsoever that the Republic and Arcelor Mittal plant closures can be attributed in any part to the effect of subject imports, apart from two unsupported statements made at the time of the closures. In a moment, we will examine the extensive evidence presented by respondents to demonstrate that factors unrelated to subject imports caused these two plants to close. First, however, it is important to note that the two statements offered by petitioners do not, on their face, point to subject imports as the cause of either closure. The fact is that the quotations of Arcelor Mittal and Republic, set forth at page 29 of petitioners' hearing presentation, clearly do not relate to subject imports or even to total unfairly traded wire rod imports:

<u>The Arcelor Mittal May 14, 2015 Statement</u>

> Arcelor Mittal Georgetown, the company's primary producer of wire rod in the United States, has been severely impacted by waves of unfairly traded steel imports from China and other countries. Even in the most recent quarter, wire rod imports rose to account for [ ] percent of the U.S. market.

The figure of [ ] percent clearly relates to total wire rod imports. Although the Staff Report does not give data for the first quarter of 2015, total wire rod imports constituted [ ] percent of ADC for 2014 and [ ] percent of ADC for 2015. Subject imports were [ ] percent of total imports in 2014 and only [ ] percent of ADC. Total unfairly traded imports (subject imports plus China) were [ ] percent of ADC in 2014 and declined to [ ] percent in 2015. So there is no case to be made that increases in subject imports, or even total unfairly traded imports, were a cause of the closure of the Georgetown mill.

Moreover, other statements by Arcelor Mittal at the time of the plant closure attribute it to non-import causes, most particularly the loss of use of the Georgetown harbor. This was testified to by witnesses from the American Wire Producers' Association. See, for example, Mr. Stauffer of Insteel (Tr. at 153):

> {T}he Georgetown mill had insurmountable problems that significantly increased its cost. We were told by Arcelor Mittal's management that high input costs as well as increased domestic competition from Nucor's state-of-the-art rod mill in Darlington were the main factors that caused the shutdown of the Georgetown mill. These factors would have lead to a closure of the mill with or without imports in the market.

And Mr. Waite, AWPA counsel (Tr. at 184-185):

> {T}here were contemporaneous communications between Arcelor Mittal and {185} Insteel before and during the time of the announcement of the closure, which identified reasons which were very different than imports as the factors leading to that decision. You will find those in Confidential Exhibit B to the AWPA prehearing brief.

See also the contemporaneous articles submitted in the AWPA Pre-Hearing Brief at Exhibits 8-12.

<u>The Republic January 17, 2016 Statement</u>

> With a negative 2016 economic forecast and the continued dumping of steel imports, Republic had no other option but to idle the Lorain plant.

The Commission will note that the statement does not mention wire rod imports. This makes sense as the Lorain facility was overwhelmingly devoted to bar production, with the products that fall into the HTS wire rod category constituting "an extremely small portion of the overall bar size range that Republic Lorain bar mill supplied to the marketplace." There is thus no reasonable basis to interpret Republic's reference to "dumping of steel imports" as anything other than a reference to dumped bar imports, not rod imports.

Moreover, there was testimony at the hearing that other Republic Lorain statements attributed the closure to factors unrelated to subject imports:

> As for Republic, public statements from the company attribute their decision to a decline in oil and gas {154} markets to which Republic was a special bar quality product supplier. Additionally, Lorain never produced sizes that we would consider to be relevant in the U.S. domestic rod market.[2]

<u>The Evidence Shows That Factors Other Than Subject Imports Fully Explain the Arcelor Mittal and Republic Plant Closures</u>

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[2] Tr. at 153-54 (Stauffer). Note that the same deficiency – failure to identify which imports harmed the company – make petitioners' reference to adjustment assistance of no probative value.

At the outset, the dramatic difference in the results of these two producers, when contrasted with the results of the rest of the industry, provides evidence that those two companies were impacted by factors other than subject imports, with which all U.S. producers competed.

But beyond that contrast, the record is replete with factual evidence – not just unsupported and self-serving assertions – that the closures of both the Republic Lorain mill and the Arcelor Mittal Georgetown mill are fully explained by factors that had nothing to do with subject imports.

A. The Arcelor Mittal Georgetown, SC Mill

The Georgetown mill closure was announced in May, 2015. At that time, unfairly traded imports were declining significantly, after the imposition in January of Title VII orders against Chinese wire rod imports. Unfairly traded imports (China and subject imports) fell by 150,856 tons during 2015.[3]

At the hearing, petitioner witnesses acknowledged that the China Orders issued in January 2015 provided relief for a temporary period from unfairly priced imports. See, for example, the testimony of Mr. Canosa of Gerdau, Tr. at 49. And petitioners' counsel stated clearly that conditions in 2015 did not warrant seeking relief from subject imports, because they had not yet begun the "surge" of which petitioners now complain.[4]

Yet it was in this period, only a few months after the China Orders, a period in which unfairly traded imports were declining and petitioners acknowledge that they had temporary relief, that the Georgetown plant closed. If unfairly traded imports had any effect on that closure decision, it could only have been the damage down in prior years by unfairly traded imports – imports that were from China, not from the ten countries subject to this proceeding.

[3] Pre-Hearing Staff Report at IV-25, Table IV-12.
[4] Tr. at 63 (Rosenthal).

But in fact the Georgetown plant had other problems, unrelated to any imports, that caused it to close. It was an old, high cost plant and it encountered one problem that sealed its fate. It relied on DRI that it imported through the Port of Georgetown. That port had become increasingly clogged with silt, to the point that it had become unusable for DRI imports unless it could be dredged at an estimated cost of $66 – $70 million. It was when the Corps of Engineers refused to make that expenditure, as did the State and local governments, that the closure decision was made. All of this is recounted in the articles in submitted in the AWPA Pre-Hearing Brief at Exhibits 8-12.

Petitioners do not deny the major silt problem. As Mr. Rosenthal said,

> I will say we're not saying that silt didn't build up in the bay leading into the Georgetown facility. That clearly has been an issue for them…[5]

And Arcelor Mittal told its customers, including Mr. Stauffer of InSteel:

> {I}t was made clear to us that the position that the {Georgetown} mill was in logistically was going to be difficult to continue to operate. In addition to that, you have the Nucor Darlington mill coming up at about the same time the Georgetown mill is going down.[6]

The coming online of Nucor's Darlington, SC mill at about the same time as the Georgetown closure, is significant for two reasons:

First, it was a low cost mill, only 100 miles from Georgetown, that had major competitive advantages over the Arcelor Mittal facility. This, as Mr. Stauffer noted, contributed to the decision to close Georgetown.

Second, the Darlington mill was competing with subject imports in the same manner as was the Georgetown plant. Yet, as the Nucor witness stated, his company was willing to spend

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[5] Tr. at 82 (Rosenthal). See also Tr. at 101 (Ms. Cannon).
[6] Tr. at 183 (Stauffer).

"tens of millions of dollars to start production at our state-of-the-art Darlington facility."[7] The fact that Nucor, facing the same subject import competition, made that investment while Arcelor Mittal decided to close is striking evidence that the Georgetown closure decision was not caused by those imports. In fact, the Nucor decision was entirely sound:

> So someone at Nucor made a very good economic analysis that said even based on the POI and the imports and where they're coming from and wherever, let's build a more efficient mill that essentially makes Georgetown redundant into that.[8]

Commissioner Broadbent made an insightful point about the interrelationship of the Georgetown plant closure and the Darlington investment by Nucor:

> To what extent can we interpret changes in the industry's capacity and production data over the POI as just a period of consolidation, as opposed to injury? I note that the closure of the Georgetown mill was right around the same {100} time as the Nucor's Darlington mill was started up.[9]

Petitioner's counsel responded that Arcelor Mittal was not consolidating, and then went on to say that "It really was an effort by the industry to consolidate."[10] But of course that's just the point. One company's old, high cost mill encountered an insuperable problem specific to its own situation – the clogging of the harbor – and had to close. And another company saw that as an opportunity to build a more efficient plant. The fact that it did so when it would have to contend with the same subject imports as did Arcelor Mittal shows that subject imports weren't the problem that would have required an efficient competitor, with no port problem, to close.

At the hearing, petitioners tried to argue that Arcelor Mittal's problem with dredging the Georgetown harbor was in part an import problem. If the Georgetown mill's profits prior to 2015 had not been hurt by imports, they speculated, Arcelor Mittal might have done periodic

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[7] Tr. at 47 (Nystrom).
[8] Tr. at 183 (Stauffer).
[9] Tr. at 99-100 (Broadbent).
[10] Tr. at 100 (Cannon).

dredging to keep silt from building up in the harbor.[11] The problem with that argument, apart from the fact that it is totally speculative, is that the imports that might have had such a pre-2015 impact on Arcelor Mittal's wire rod profits could only have been Chinese imports, not subject imports.

In sum, two facts are clear. First, unfairly traded imports, which were declining at the time and which the petitioners themselves consider did not warrant relief in 2015, played no role in the Arcelor Mittal closure. Second, the decision to close the Georgetown plant is fully explained by the harbor/silt closure and by the coming on line of the nearby, much more cost-efficient Nucor mill.

B. The Republic Bar Mill at Lorain, Ohio

The facts concerning the closure of Republic's bar mill at Lorain, Ohio – and with it, the minor ancillary production of a product with a wire rod HTS classification – are so clear that petitioners spent little time discussing it. But this does not mean that the Lorain closure is insignificant for this case. The Commission must remember that the decline in market share alleged by petitioners – only [ ] percent over the three year POI – is so tiny[12] that excluding Republic alone means that the industry shows a market share increase over the POI:

At the hearing, Mr. Shields (who had worked at the Lorain facility), made three basic points:

First, the Lorain facility was a bar mill, and its production of the product classified as wire rod in the HTS was an insignificant portion of the Lorain operations:

> As discussed in our brief, the Republic Steel facility produced three main products – semi-finished tube-rounds, large diameter hot rolled {141} straight bars on their 20-inch valve and hot-rolled

[11] Tr. at 84 (Nystrom), 101-102 (Rosenthal).
[12] Tr. at 140-141 (Shields).

> cold product on their 9/10-inch valve. A small percentage of the coil product falling into the HTS wire rod category.[13]

Second, given the tiny role of wire rod in the Lorain operation, it is beyond dispute that the closure of the facility was caused by issues in the bar market:

> In January 2015, due to the crash of the oil and gas sector, U.S. Steel idled its Lorain tubular operations. This idling resulted in … the subsequent exit of {Republic's} supply of tube-rounds…
>
> {T}he Republic Lorain 20-inch bar mill continued to struggle with production due to incredibly depressed demand levels for large diameter bars and specifically for the oil and gas sector. The core production on the Lorain 9/10-inch mill also experienced a demand decline, but not to the same level as the large diameter bar mill. Republic needed a bar volume output spread across both of these mills to continue rolling operations at Lorrain.
>
> With bar demand for the large diameter bar almost totally nonexistent in March 2016, Republic shut down production at both bar mills. This shutdown was related to {142} a decreased volume demand across all hot rolled sizes with the biggest market decline in the large bar sizes, 3-inch to 6-1/2-inch. The size range involved in this proceeding, coil diameter through 19 millimeters, was an extremely small portion of the overall bar size range that Republic Lorain bar mill supplied to the marketplace.[14]

Third, the Republic Lorain facility, even to the small extent that it did produce a product with an HTS rod classification, did not compete with subject imports:

> Republic Lorain mill was just not competing with rod mills, domestic and foreign, including the 10 rod mills involved in this investigation on the highest hot rolled wire rod volume sizes of 7/30 seconds {sic; should be 7/32} quarter-inch, and 9/30 seconds {sic; should be 9/32}. Most importantly, specific to the scope of this proceeding and the steel supply from the Republic Lorain mill of hot rolled sizes of .297 to 19 millimeters and excluding free-cutting grades, the Republic Lorain facility competed only on a negligible basis with hot rolled rod imports from these 10 countries.

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[13] Tr. at 140-141 (Shields).
[14] Tr. at 141-142 (Shields).

> As Republic did not compete with imports from these countries, the rod imports from these 10 countries had no factor in the decision-making for the shutting down of the Lorain bar mills. The shutdown of Republic's Lorain bar mills in 2016 was a demand issue and clearly had nothing to {143} do with the competition from the wire rod imports that are the subject of this proceeding.[15]

Neither Republic nor petitioners have provided facts to rebut any of the foregoing. Indeed, after having been asked by Staff to provide information about the breakdown at Lorain between wire rod and other products,[16] [ ][17]

Such asserted opinion statements, without any explanation or factual support, provide no basis for the Commission to make a decision.

Finally, there is one further and decisive point of evidence that the Lorain closure was caused by bar problems and not by any problems – caused by subject imports or otherwise – in its tiny wire rod production. The fact is that Republic's operating results on its wire rod production were [ ] than those of other U.S. wire rod producers, as shown by Republic's questionnaire response in the preliminary investigation.[18] Republic's Lorain closure came in March 2016, after a period in which its operating results [ ] throughout the POI.[19] And its average sales value of commercial shipments [ ], compared to an overall wire rod industry decline of [ ] percent.[20] It is simply not credible to contend that a decision to close an entire bar facility would be based in any part on the operating results and price data that show no material injury for a product that constitutes a tiny sliver of the facility's operations.

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[15] Tr. at 142-143 (Shields).
[16] Nov. 16, 2017 email from Joanna Lo to Ted Thieleas of Republic.
[17] Republic, which is not a petitioner, has not filed a response to the final investigation questionnaire.
[18] Republic, which is not a petitioner, has not filed a response to the final investigation questionnaire.
[19] Republic Response to Preliminary Investigation U.S. Producers' Questionnaire, at 22.
[20] Pre-Hearing Staff Report at VI-9, Table VI-3.

C. The Legal Standard for Analyzing These Plant Closures

Commissioner Schmidtlein quite rightly posed the question whether it is enough to find that subject imports' effect on the decisions to close the Arcelor Mittal and Republic mills is:

> … a cause. It doesn't have to be the only cause, it doesn't have to be the primary cause.[21]

Petitioners' counsel, of course, said that any slight evidence would suffice to establish causal link, even unsupported assertions by interested parties, and that "a" cause is all that is required.

Petitioners misunderstand the difference between the standard for reaching the ultimate statutory conclusion and the standard for finding the facts from which that ultimate conclusion is to be drawn. Clearly, sufficient causation of material injury is found where imports are "a" cause, meaning a cause that is significant, but not necessarily the primary cause. However, in reaching that conclusion, the Commission needs to develop an accurate factual record and, in so doing, must make a reasonable judgment as to the existence or non-existence of each fact. Thus, the Commission decides on a preponderance of the evidence such factual questions as:

- Did imports and market shares increase or decrease?
- Was underselling sufficient in extent and degree to be significant?
- Was a particular product within the appropriate "like product"?

As to such questions, the Commission would not take the petitioner's position simply because there was some evidence in the record to support it. Rather, the Commission would assess which answer was supported by the balance of the evidence.

Whether subject imports played a sufficient role in causing a decision to close a plant is an issue on which the Commission is to weigh the evidence and which answer is supported by

[21] Tr. at 181 (Schmidtlein).

the balance of the evidence. This is what the Commission has done in cases addressing the plant closure issue:

- In Liquid Sulfur Dioxide from Canada,[22] subject imports were present in the market, including sales at lower prices than those of domestic producers. In addressing the issue of why Rhodia, a major U.S. producer, left the industry, the Commission found that it do so rather than meet the costs of complying with environmental concerns. Given the presence of unfairly priced imports, it could have been argued – as petitioners argue here as the Arcelor Mittal's cost of dredging the Georgetown harbor – that subject imports might have reduced Rhodia's profitability and thus made it more difficult to address the environmental situation. Under the theory advanced here by petitioners, any such impact on operating results would have been sufficient to find subject imports to be "a" cause. Instead, the Commission weighed the evidence and found that, on balance, the closure was the result of environmental concerns.

- In Titanium Sponge from Japan and Kazakhstan,[23] the Commission found that ATI's cessation of production was "a business decision due to the cost disadvantages of a non-integrated facility, and was not a result of low-priced imports. In any case where a closure is related to cost disadvantages, there is potential to find that low-priced subject imports are "a" cause, simply because their low price makes it more difficult for a high-cost domestic producer to compete. What the Commission musts do, however, is to weigh the competing factors to determine the degree of significance of imports versus other causes.

Here, that weighing of causes is easy with respect to both Arcelor Mittal and Republic. As to Arcelor Mittal, fairly priced imports were declining and petitioners acknowledge that they were in a period (in early 2015) where they had obtained temporary relief from unfair imports. The Georgetown mill could not solve its harbor problem and was not competitive with the new, state-of-the-art nearby Nucor plant. Those problems would have forced the closure even if subject imports had not been present.

As to Arcelor, the tiny wire rod production – even if it had problems with subject imports or otherwise – could not cause a closure of a plant devoted overwhelmingly to bar products.

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[22] Inv. No. 731-TA-1098 (Preliminary), USITC Pub. 3826 (2005).

[23] Inv. No. 701-TA-587 and 731-TA-1385-1387 (Preliminary), USITC Pub. 4736 (2017). Note that both Sulfur Dioxide and Titanium Sponge were decided under the more minimal preliminary investigation standard. Also, petitioner's counsel argued that Titanium Sponge was based on the company's statement that the Issue was not caused by subject imports. The decision does not say that, nor should it. As discussed earlier, the Commission must examine the facts and not rely on unsupported assertions.

Moreover, the small wire rod production was doing relatively well and demonstrably did not have problems – whether caused by subject imports or not – that would have caused the closing of the much larger bar operation.

APPENDIX C

Commissioner Broadbent (Tr. 131, lines 15-17). {To Petitioners} so you're arguing that we have both critical circumstances and post-petition effects. Can it be both at the same time…?

Commissioner Broadbent's question appropriately highlights one of the complete inconsistencies in Petitioners' arguments. On the one hand, Petitioners claim that there has been a "dramatic" "surge" in subject imports[24] while also claiming post-petition effects manifested in the form of improvement in the U.S. industry's financial performance.[25] When evaluating critical circumstances, Petitioners' positions are inapposite and their arguments with respect to critical circumstances should be disregarded.

Moreover, when critical circumstances are evaluated specifically with respect to the United Kingdom, it is clear there is no basis to conclude that imports from the U.K. would "likely undermine seriously the remedial effect" of the order. As discussed in British Steel's Post-Hearing Brief, imports from the U.K. amounted to just 1% of total U.S. domestic consumption, a share that actually decreased from 2016-2017. Imports as a whole from the U.K. are at a negligible level and decreased over the period. When the Commission properly examines the domestic industry as consisting of two like products (one defined as 1080 TC/TB, as discussed in the Post-Hearing Brief above), the United Kingdom must be excluded from this investigation on the basis of negligibility.

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[24] Tr. at 38, line 20 (Rosenthal).
[25] Tr. at 22-23 (Price).

APPENDIX D

COMMISSIONER WILLIAMSON (Tr. at 91): "Okay. Thank you. Let me turn to wire rod for tire cord and bead. Can other grades below 1080 be used for tire cord and tire bead?"

COMMISSIONER WILLIAMSON (Tr. at 92): "Okay. What uses determine the grade of tire or bead? And is there any production equipment adjustments needed to make tire cord and tire bead wire rod? And if you wanna hit that post-hearing, I'll accept that, too."

COMMISSIONER WILLIAMSON (Tr. at 93): "Okay. I was wondering, do difference between the EAF and BOF production processes impact the requirements that in - by end users. In other words, do your end users say, you gotta make it by this process or by that process?"

COMMISSIONER BROADBENT (Tr. at 103): "So I'd like to go back to the like product argument with regard to 1080 tire cord and tire bead. So it's my understanding that in 2002, there was a scope exclusion in the wire rod case for this product and that in 2014, it was not excluded, but I don't believe anyone raised a like product argument in that case. So my question is what has changed since 2002?"

COMMISSIONER BROADBENT (Tr. at 105): "So we did collect separate data for tire cord and bead. If we were to find a separate like product, do you think the record is there to go affirmative on it, given the non-subject in the market?"

COMMISSIONER BROADBENT (Tr. at 105): "If we were to split the products and find that there is a separate like product for tire cord and bead, based on the data that we collected, and the fact that non-subject gained market share in that market, U.S. lost, but so did subject, do you think the record would support an affirmative determination if we were to find separate like products?"

COMMISSIONER WILLIAMSON (Tr. at 118): "Okay, thank you. Just a couple of quick questions on the tire cord and tire bead. Do any of your firms source billets from BOF, from the BOS process to produce wire rod, and how often do you buy billets for wire rod, particularly for the 1080 or other grades? If you wanted to do it post-hearing, it's fine."

COMMISSIONER WILLIAMSON (Tr. at 119): "Okay. Are any U.S. producers currently pursuing certifications or capabilities to produce tire cord of a quality greater than the 1080 grade, and again that might be a post-hearing one too. And then Table 1-8 shows U.S. production of grade 1080 and higher. Do we know if this production involved any electric arc furnaces? So I'm asking not what you're capable of, but what's actually happening."

COMMISSIONER WILLIAMSON (Tr. at 203): "Okay. They do say this morning, they could - now whether anybody's actually doing it - they use the electric arc furnaces to make 1080 if you have different inputs, the DRI or - is that – do you agree with that?"

VICE CHAIRMAN JOHANSON (Tr. at 216): "Given the Commission's consistent single like products definition for wire rod, to what extent is respondent's like product argument premised on technological or market changes since prior investigations? Or do you all simply contend that the Commission got it wrong when it rejected similar arguments in the past?"

VICE CHAIRMAN JOHANSON (Tr. at 221): "Thanks, Mr. Cameron. Could all please explain how the use of a blast oxygen furnace versus an electric arc furnace to produce raw steel in imparts differences in the resulting wire rod produced from the raw steel? And do you all have any industry or metallurgical literature that supports and describes the differences that you identified, particularly as they relate to tire cord?"

COMMISSIONER WILLIAMSON (Tr. at 225): "So I want to - thank you. And so if we find that the domestic producers do not produce grade 1080 tire cord and tire bead wire rod, how should the - how should that affect the Commission's domestic like product analysis?"

British Steel very much appreciates and commends the Commission's attention to the important issue that 1080+ TC/TB, as defined, is a separate like product. The Commission appropriately asked specific questions and collected data on this issue in the final phase of this investigation thereby providing parties, and the Commission, a more robust basis to evaluate the like product issue. At the hearing, a number of parties, including producers, importers and industrial users provided detailed information and testimony demonstrating that 1080+ TC/TB is a factually, functionally and legally distinct product wholly unlike the standard wire rod which petitioners repeatedly have emphasized that this investigation is really about.[26] The Commission now has near complete informational coverage on this issue, unlike any previous time it considered the matter. In this regard, British Steel herby explicitly concurs with and incorporates the arguments on these points being made by the AWPA, KISWIRE and POSCO.

British Steel contends that the record is clear that 1080+TC/TB is a separate like product. Contrary to petitioners' unsupported contentions, 1080+ TC/TB is not simply another wire rod product within a group of the standard products they produce and sell on a mass scale. Petitioners claim to make 1080 tire cord and bead, based on questionnaire responses and public statements, it appears some of them did produce and sell wire rod within the product defined as 1080+ TC/TB, specifically 1080 tire bead. British Steel takes these U.S. producers at their word that they have produced and sold some quantity of 1080+ TC/TB during the POI.

As such, and in response to Commissioner Broadbent's and Commissioner Williamson's questions, British Steel respectfully requests that the Commission makes this like product finding and determine whether the domestic 1080+ TC/TB industry is materially injured or threatened with material injury by reason of subject imports. In doing so, analysis of the domestic industry

[26] See, e.g. Preliminary Conference Tr. at 129 in which counsel for petitioners discusses that this case is about "conventional low, medium and high carbon grades….used to make products that range from PC strand to fencing to small wire baskets." (Prelim Tr. at 129) (Mr. Price).

data for this product leads to only one conclusion—that the domestic industry is not materially injured, nor threatened with material injury by reason of subject 1080+ TC/TB imports. Perhaps most telling on this point is that subject imports' market share for 1080+ TC/TB *declined* while non-subject sources gained market share, as Commissioner Broadbent correctly notes.[27] Moreover, Petitioners go so far as to essentially dismiss the role of 1080+TC/TB in the marketplace: "but we want you…to *understand the relatively small portion of the market* that 1080 tire cord and bead represents in this industry and imports overall. As you look at that 700,000 tons of imports that came in from the subject imports, understand *how minuscule a proportion* of that import surge was represented by 1080 tire cord and bead." [28]

A number of the questions excerpted above regarding the production and use of 1080+ TC/TB were directed to petitioners, presumably because they have not provided much information on these points up until this point. British Steel thoroughly addressed these questions in its Post-conference Brief,[29] its Foreign Producers' and U.S. Importers' Questionnaire Responses and in its Pre-hearing Brief.[30] In doing so, British Steel provided extensive information and data regarding the production process for 1080+ TC/TB, British Steel's reasons it finds it necessary to use a BOF (rather than an EAF) to produce the product and the technical requirements for production as dictated by our customers. It is British Steel's experience that 1080+ TC/TB, as defined, cannot be consistently produced to the specifications required by its customers in an EAF. In response to Commissioner Johanson's request for articles on this issue, please see Exhibit 1 to this response.

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[27] To British Steel's knowledge, neither the closed Arcelor Mittal Georgetown plant nor the closed Republic plant produced 1080+ TC/TB.

[28] See, e.g., Testimony of Mr. Rosenthal (Tr. at 40) (emphasis added). While British Steel strongly disagrees that there was any "surge," petitioners counsel make clear that 1080 imports did not have a material impact on the market.

[29] See British Steel Post-Conference Brief at 22-30, and accompanying exhibits.

[30] See British Steel Pre-Hearing Brief at 21-29, and accompanying exhibits.

While petitioners may assert otherwise, their lack of consistent production or even ability to certify to the purchasers betrays their claims. To the extent that a producer may use a billet purchased from a BOF producer, as Nucor claimed to have done[31] (Tr. at 46 (Nystrom)), that would only support the point that production in a BOF is necessary. British Steel is not aware of any supplier to the U.S. market producing 1080+ TC/TB, as defined, using an EAF. While a company may claim differently on a website, British Steel certainly has not confronted such 1080+ products in the U.S. market.

In this regard, and in response to Commissioner Johanson's question, a great deal has changed since the Commission last truly considered the 1080 like product issue. Frankly, pretty much everything has changed. The 1080+ wire rod product has changed because the uses have changed, as reflected in the laws/regulations under CAFE standards. The Commission heard testimony from tire producers, the U.S. Tire Manufacturer's Association and suppliers to tire companies (of which British Steel is one supplier), about the leaps in tire sizes and demand for stronger, lighter TC/TB.[32] British Steel and other producers have modified and improved their production to meet these requirements. Moreover, for the first time, the Commission has actual data on the record providing a solid basis for analysis. This is by no means a retread, if you will, of old arguments. The product before the Commission in this investigation is unlike even that previously considered. The data are unlike that previously considered. The testimony and extensive briefs on this issue, including that of British Steel, are unlike that previously considered. This is nothing like the China investigation in which no one contended the issue.

[31] Tr. at 46 (Nystrom).
[32] See, e.g. Testimony from Ms. Norberg of the Tire Manufacturers Association, Tr. at 171-173. See also Exhibit 2 to this Post-Hearing Brief for statistical data on tire production and shipment trends from 2011-2016. The Excel spreadsheet summarizes the data.

In addition, British Steel respectfully contends that the statute requires that the Commission to recalculate the data for each like product (standard wire rod and 1080+ TC/TB, respectively) to perform a negligibility analysis for each like product.[33] These data already are on the record and no further data is required.

[33] *See* 19 U.S.C. §1677(24)(A)(i) (noting that negligibility should be measured for imports "corresponding to *a* domestic like product identified by the Commission," which directs the Commissioners to consider negligibility separately for each like product rather than for all imports collectively). *See also Certain Kitchen Appliance Shelving and Racks from China*, Inv. Nos. 731-TA-1154 (Final), USITC Pub. No 4098 (Aug. 2009) (where the ITC found appliance shelving and racks to be separate domestic like products and considered the negligibility of each separately); *Hydrofluorocarbon Blends and Components from China,* Inv. Nos. 731-TA-1279 (Final), USITC Pub. No. 4629 (Aug. 2016) (where the ITC found HFC blends and components to be separate domestic like products and considered the negligibility of each separately); and *Certain 4,4-Diamino-2,2-Stilbenedisulfonic Acid Chemistry from China, Germany, and India*, Inv. Nos. 701-TA-435 (Preliminary), USITC Pub. No. 3608 (July 2003) (where the concurrence viewpoint found multiple like products and analyzed the negligibility of each separately). Even where the ITC did not ultimately find a separate like product, it engaged in a hypothetical analysis of "what the negligibility ratio would be should the Commission find that black plate is a separate domestic like product" as part of its negligibility consideration. *See Cold-Rolled Steel Flat Products from Brazil, China, India, Japan, Korea, Netherlands, Russia, and the United Kingdom,* Inv. Nos. 701-TA-540 – 544 and Inv. Nos. 731-TA-1290 (Preliminary) USITC Pub. No. 4564 (Sept. 2015).

APPENDIX E

Subject Imports Partially Replaced Chinese Imports

> **BY COMMISSIONER BROADBENT (Tr. at 62): "{T}he domestic industry did not lose significant market share over this current Period of Investigation. Given that there wasn't a substantial loss of market share to current subject imports over the period, aren't we really just talking about market share losses that were caused by the imports from China?"**
>
> **BY COMMISSIONER BROADBENT (Tr. at 66) (Concerning petitioners' slides showing U.S. purchasers decisions to buy subject imports): "But they're basically shifting from buying from China to buying from subject imports?"**
>
> **BY COMMISSIONER JOHANSON (Tr. at 193): "What authority is there for the proposition that unfairly traded imports cannot cause injury when they replace existing unfairly traded imports…?"**
>
> **BY COMMISSIONER WILLIAMSON (Tr. at 236): "Please explain the argument on page 19 of your Pre-hearing Brief that domestic producers should not have expected to have gained all of the volume left by the Chinese imports' disappearance from the market."**

The Commission has historically found that subject imports did not cause adverse volume effects, even where those subject imports increase, where that increase came at the expense of other imports, not at the expense of domestic producers. Here the record is clear that subject imports' increase – both in volume and in market share – did not come at the expense of domestic producers:

- The increase in subject imports over the POI was less than the decline in non-subject imports as a whole and less than the decline in imports from China[34]:

[34] Prehearing Staff Report at IV-4, Table IV-2

Source	**2014 – 2016 Change**
Subject Countries	[ ]
Non-Subject Countries	[ ]
China	[ ]

- This is equally true for the 2014-2015 changes in volume, which is particularly important in analyzing both volume effects and price effects. All of the decline in U.S. wire rod prices occurred in 2015 and the closure of the ArcelorMittal Georgetown plant (which accounts for more than all of the POI declines in U.S. industry volume and market share) occurred in that period, where subject imports were taking volume entirely from other imports[35]:

Source	**2014 – 2015 Change**
Subject Countries	[ ]
Non-Subject Countries	[ ]
China	[ ]

- Putting aside the two companies that exited the wire rod business (ArcelorMittal and Republic), the petitioning domestic wire rod producers did not lose volume or market share during the POI, and thus suffered no adverse volume effects from subject imports.[36] Petitioners' volume increased by [ ] tons and they gained [ ] percentage points in their share of the U.S. merchant market.

- Finally, purchasers' answers to the Commission's question concerning purchases of subject imports instead of domestically produced wire rod confirm that little of the 2014 to date sales of subject imports represented shifts from domestic purchases to subject import purchases:

[35] Id.
[36] Pre-Hearing Staff Report at IV-30, Table IV-14, adjusted by U.S. commercial shipments data from ArcelorMittal's and Republic's response to Question II-7 of the U.S. Producers' Questionnaire.

2014 to Date	
Total quantity purchased instead of domestic	[ ][37]
Total subject imports	[ ][38]
Percentage purchased instead of domestic	[ ]

Thus, it appears that more than [ ] percent of the U.S. purchases of subject imports were made instead of purchasing other sources of supply, which could only be non-subject imports.

On their face, these figures would seem dispositive of the question whether the domestic industry suffered adverse volume effects caused by subject imports. However, petitioners advance the novel argument that the Commission should ignore the clear fact that subject imports took volume entirely from non-subject imports, on the ground that the largest decline of non-subject imports was from China, which were unfairly traded imports. Since those Chinese imports left the market because of Title VII orders imposed at the start of 2015, the petitioners argue, they should have benefitted from the decline of the Chinese imports, and subject imports

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[37] Pre-Hearing Staff Report at V-37, Table V-13. This figure undoubtedly overstates the volume of subject imports that had an impact on domestic industry volume, for several reasons:

- It is not a "net" figure, because the question does not ask what volume of domestically produced wire rod a purchaser bought instead of subject imports. *See* Tr. at 209-11 (Cunningham).
- Some purchasers were clearly confused by the question. *See* Tr. at 209 (Moffitt).
- And it is clear that a substantial portion of the [ ] tons was bought for reasons other than price. *See* the non-price explanations given in Table V-13 by [ ] percent of that total, that were purchased in part for non-price reasons. *See* also the non-price reasons given by Messrs. Stauffer (Tr. at 151), Moffitt (Tr. at 154-155) and Waite (Tr. at 215-216).

[38] Id. At IV-4, Table IV-2. This analysis responds to the question posed by Commissioner Broadbent (Tr. at 208): "Table V-13 of the purchasing report contains information from purchasers indicating that they source substantial volumes from subject imports over the POI instead of the domestic industry, with many of these firms stating that low import prices were a primary reason. Can you explain how we should interpret their data?"

caused material injury by depriving them of that benefit. That argument is wrong on the facts and wrong on the law.

First, and perhaps most important, petitioners were not deprived of the benefit they might have expected from the decline in Chinese imports. When imports from one country are withdrawn from the market, it provides an opportunity for all other competitors to gain volume. The amount of gain that a competitor or group of competitors might reasonably expect to achieve is best measured by their share of the market before the entry of the Title VII orders forced the Chinese out – that is, their market share in 2014.

The petitioners in this case[39] had [ ] percent of the U.S. wire rod market in 2014. When the Title VII orders forced [ ] tons of Chinese wire rod out of the market, the reasonable expectation would have been that petitioners would gain [ ] percent of that exited [ ] tons, or a 2014-2016 increase of [ ] tons. Instead, petitioners gained a far larger [ ] tons, or [ ] percent of the exited Chinese volume. There is simply no way that petitioners can argue that they were deprived of the benefit they could reasonably expect from the China Title VII orders. They got that benefit – and much more.

The petitioners' argument is also wrong on the law and directly inconsistent with Commission precedents. The issue is not whether the imports that subject imports replaced were fairly traded or unfairly traded. This is not a question of fairness; that is a Commerce Department issue. The question for the Commission is purely one of economic impact: did the increase in subject imports come at the expense of domestic producers' volume? Here it

[39] Not including ArcelorMittal or Republic. ArcelorMittal exited the industry shortly after entry of the China Title VII orders and thus obviously would not have been able to take any of the departing Chinese volume. And Republic made a small quantity of bar product which, while HTS-clarified as wire rod, did not compete with wire rod imports. See Tr. at 142-143 (Shields).

obviously did not. The petitioners' volume and market share both increased over the POI. And that increase got them a greater percentage of the volume left by China than their 2014 U.S. market share would have predicted.

This is not a new issue for the Commission. It considered almost the same volume and market share fact patterns as that presented here, and reached a unanimous negative determination, in Certain Carbon Steel Butt-Weld Pipe Fittings from France, India, Israel, Malaysia, Korea, Thailand, the United Kingdom and Venezuela.[40] There both subject imports and U.S. producers' merchant market shipments and merchant market shares increased during the POI, as was the case here. The Commission found that the increase in subject imports' volume and market share did not come at the expense of the domestic industry. Rather, "we find that the increases in subject import and domestic market shares between 1991 and 1992 resulted from the rapid decline of imports of Chinese and Thai (non-AST) fittings following suspension of liquidation on those products in 1991."[41]

Significantly, the Commission, far from finding that the domestic producers had some sort of right to capture the volume available as a result of orders entered against the Chinese and Thai imports, viewed the decline in those non-subject imports as a condition of competition in the U.S. market:

> Greatly diminished volumes of imports from China and Thailand, two countries that were formerly important sources of supply, is another condition of competition distinctive to the industry. Carbon steel butt-welded pipe fittings from these countries are currently subject to antidumping orders…During the period of

[40] Inv. Nos. 701-TA-360 and 361 (Final) and 731-TA-688-695 (Final), USITC Pub. 2870 (April 1995).
[41] Id., Views of the Commission, at I-23.

> these investigations imports from China and Thailand subject to these outstanding orders were virtually eliminated.[42]

The same treatment of Chinese imports is appropriate here. Their exit from the market, whether from Title VII orders or some other cause, is simply a condition of competition. It creates no right or entitlement on the part of U.S. producers to claim all or any part of the former Chinese volume. And where, as is the case here, the domestic producers' increased volume represented a percentage of the former Chinese volume larger than their beginning-of-POI market share, the U.S. industry did in fact benefit from the Chinese market exit to the extent they might have been expected to benefit.

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[42] Id., Preliminary Staff Report, at I-10.

APPENDIX F

Subject Imports Have Neither Depressed Nor Suppressed Wire Rod Prices

> **BY COMMISSIONER SCHMIDTLEIN (Tr. at 76): "{W}hen you look at unit COGS, they declined more than the AUVs of the domestic suppliers.**
>
> **So can you respond to the argument that when you look at unit COGs, that's what accounts for the decline { 73 } in price, since you see a greater decline whether you look at the merchant market or the total market in unit COGs?"**
>
> **BY COMMISSIONER SCHMIDTLEIN (Tr. at 76): "AWPA says that throughout 2016 and into late 2017 there have been numerous price increases, so can the witnesses talk about those…"**
>
> **BY COMMISSIONER SCHMIDTLEIN (Tr. at 79): "So I'm just curious, given that demand was not going up during this time, why did you think you could put through price increases?"**
>
> **BY COMMISSIONER JOHANSON (Tr. at 112): "Could you all please explain what events contributed to changes in scrap prices since 2014?"**
>
> **BY COMMISSIONER JOHANSON (Tr.at 114): "Do scrap prices rather than any post-petition efforts explain price increases later in the period of investigation?"**
>
> **BY COMMISSIONER JOHANSON (Tr. at 198-199): "Petitioners argue that unit net sales fell to a greater degree than raw materials from 2014 to 2016, leading to a decline in the industry's operating income…Is this evidence of price depression?"**
>
> **BY COMMISSIONER WILLIAMSON (Tr. at 200): "Petitioners have said subject imports have squeezed the domestic industry profit margins. Are they wrong about that?"**

There is really no doubt on the record of this proceeding that:

- At a time of falling domestic demand, with U.S. industry COGs also falling sharply (and by a greater percentage than the average unit value of sales), domestic producers would not have been able to implement price increases. Therefore, subject imports did not suppress price increases that otherwise would have occurred. The Commission correctly reached this conclusion in its Preliminary Determination,[43] and no facts have been presented that would alter this conclusion.

- With respect to price depression, wire rod price fell from the beginning of 2014 through the end of 2015, then turned up and have been rising ever since. Subject imports did not cause these price movements, either down or up. The 2014-2015 price decline came at a time when, as petitioners have acknowledged, unfairly traded imports were not a problem and did not warrant petitions for Title VII relief. Rather, the wire rod price changes correlate precisely with the movement in scrap steel costs, which fell earlier and more steeply and then pulled down wire rod prices in the 2014-2015 period. Then, when scrap steel prices turned up at the end of 2015 and continued up thereafter, wire rod prices also rose. There is no correlation between wire rod prices and unfairly traded imports, which fell in volume in the 2014-2015 period of wire rod price decline and rose in volume in 2016 when wire rod prices also rose. At the hearing, there was substantial agreement between petitioners and respondents as to this scrap price/wire rod price correlation – Commissioner Williamson's question – concerning the petitioners' allegation that subject imports squeezed their profit margins – is a useful starting point for this analysis. What squeezed the domestic producers' profit margins was a decline in wire rod prices, as the Staff concluded in their variance analysis.[44] But that alone tells us nothing about causation by subject imports. The question is: did subject imports contribute significantly to that decline in wire rod prices. The record clearly demonstrates that the 2014-2015 fall in wire rod prices that began in 2016 and continues today, was precisely correlated with and fully explained by movements in the price of steel scrap.

There was a striking degree of agreement in the hearing that purchasers and wire rod producers both follow clearly the movements in scrap steel prices, and that those scrap steel price changes are the fundamental factor in the negotiation of wire rod prices. On the purchaser side, witness after witness made this point:

> Ms. Korbel, Executive Director of the American Wire Producers Association (Tr. at 145-146): "I also want to emphasize the importance of steel scrap prices in establishing wire rod prices…We hope that you will look carefully at the correlation of scrap price changes and wire rod price changes. Because our members recognize the close relationship between the cost of scrap

[43] Preliminary Determination, Views of the Commission at 50.
[44] Pre-Hearing Staff Report at VI-17.

> and the domestic industry's wire rod prices at almost every annual meeting of the Association I invite economics experts to talk about the scrap market, including the Institute of Scrap Recycling Industries. It is a topic of great importance to {146} our members and to this case as well."
>
> Mr. Stauffer of Insteel Industries (Tr. at 152): "Negotiations with the domestic mill always start with the price of scrap. Did the scrap price go up or did it go down compared to last month? Rod prices fluctuate based on a monthly change in scrap and other metallic prices published by the American Metal Market."
>
> Mr. Moffitt of Heico Wire Group (Tr. at 157-158): "Domestic pricing is driven by monthly changes in the price of steel scrap, specifically the price of Chicago shredded as reported by American Metal Market…
>
> As a result, purchasers clearly monitor scrap prices for any indication of likely changes in rod prices. The trends in scrap prices between 2014 and today are closely correlated with wire rod prices and show that domestic prices declined in 2014 and '15 as a direct result of declines in the prices of steel scrap. Scrap prices began to increase in 2016 and they have continued to rise in 2017.
>
> Wire rod prices have followed this same trend as evidenced by the numerous price increases announcements {158} issued by the domestic mills in 2016 and 2017."
>
> Mr. Johnson of Mid South Wire (Tr. at 202): "I would say that scrap is the driving factor that drives their cost and their price and the percentage of margin they have on their product will reduce, as that price of scrap comes down, it reduces their sale price."

The same analysis was given by the domestic industry. See, for example, the testimony of Mr. Armstrong of Keystone (Tr. at 75):

> "Personally, it's the customers that try and drive the relation between scrap and the prices, it's not us…And whenever scrap goes down, it's the customers who come knocking on the door and say, hey, scrap has gone down. You should lower your prices."

Indeed, Mr. Ashby of Keystone emphasized that steel scrap prices are the only thing that purchasers understand and use in the bargaining over wire rod prices (Tr. at 115):

> "What the industry has done a really good job of telling our customers what happens with scrap and prices certainly have moved up and down with that independently, based on whatever happens with scrap. But I want to make clear that that's not the only costs that we have in our business…And in the end, scrap's just a very small – well, it's a big part of that, but it's certainly a part that our customers understand. And when we try to describe other costs, it really doesn't matter."

This acknowledged use of scrap steel prices to negotiate wire rod prices is reflected in the extremely close correlation during the POI between scrap prices and wire rod prices. This is apparent from comparing the movement of scrap prices (shown at V-8 to V-20, Tables V-3 to V-10) of the Pre-Hearing Staff Report.[45]

Both scrap prices and wire rod prices declined from their highest points at the beginning of 2014, both reaching bottom at the end of 2015 or the first quarter of 2016. The scrap price declines [ ] greatly exceeded the wire rod price declines [ ], evidencing the fact that the scrap prices were pulling down the wire rod prices. The extreme decline in the price of scrap was testified to by Mr. Armstrong of Keystone (Tr. at 113):

> "On the supply side, you can get to a point which happened…something like 12 to 18 months ago, where the price of scrap got so low that literally it was completely not worth the while of the scrap merchants to even supply it…
>
> And so that again created a bounce at the bottom and scrap came up…"

It must be emphasized that the entire period of wire rod price decline, concluding at the end of 2015, came at a time when petitioners' counsel emphasized that there had as yet been no

[45] *See* the comparative table at p.16 of British Steel's Pre-Hearing Brief.

injurious surge of unfairly traded imports and the petitioners did not believe that filing trade cases in 2015 was warranted.[46]

At the beginning of 2016, scrap prices turned up, and wire rod prices followed them up. This upward trend has continued, as the Staff Report shows and as Mr. Johnson of Mid South Wire testified (Tr. at 148):

> "Generally speaking, scrap prices have been increasing since the first quarter of 2016 and Petitioners have been announcing price increases for wire rod almost on a monthly basis."[47]

Mr. Nystrom of Keystone candidly confirmed that increasing scrap prices were pulling up wire rod prices (Tr. at 80):

> "And, as scrap prices go up, we're already under tremendous margin pressures. We have to do everything we can to try to raise that price…{T}he one thing you can't do as a steel mill is lose volume or capital-intensive business. So you know we're forced to lower prices to maintain volume and likewise, when the scrap goes up, yes, we raise prices…"

And, lest there be any doubt, Mr. Rosenthal confirmed this in his response to Commissioner Schmidtlein's question about wire rod price increases in 2016 (Tr. at 80)"

> "2016 was all scrap increase driven, as far as I can tell."

Thus there is no doubt, indeed no real disagreement about what drove the movement of wire rod prices down in 2014-2015 and up in 2016-2017. It was not subject imports. It was the movement of scrap steel prices.

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[46] Tr. at 63 (Rosenthal).

[47] At the hearing, several petitioner witnesses tried to argue that they had been unable to implement price increases announced during the 2016-2017 period. *See* Tr. at 76-77 (Armstrong), 79 (Rosenthal). But the Staff Report, particularly the data on pricing products, shows that petitioners were able to increase prices steadily after the scrap steel prices turned up at the start of 2016.

One final point. Petitioners at page 28 of their hearing presentation try to confuse the issue by presenting a graph that shows a 2014-2016 decline of industry average net sales value slightly greater than the decline average cost of raw materials. Two points need to be recognized.

First, the new material cost average is not a publicly visible figure (like scrap steel cost) that can be used in price negotiations. See the testimony of Mr. Ashby quoted above (Tr. at 115), where he complains that purchasers can't be persuaded to look at costs other than the published scrap steel prices ("And when we try to describe other costs, it really doesn't matter").

Second, from the standpoint of the producers' profit margins, it is the percentage declines in sales value vs. COGs, not the dollar declines. See British Steel Pre-Hearing Brief at 14. The percentage decline in COGs during the POI was greater than the percentage decline of AUV of sales.

Exhibit 1

2. T. Takahashi et al., "Development of High Tensile Strength Galvanized Wire for Bridge Cables", Seitetukenkyu, 332(1989), 53-58.
3. G. Langford, "Deformation of Pearlite", Metall. Trans., 8A(1977), 861-875.
4. I. Ochiai, S. Nishida and H. Tashiro,"Effect of Metallurgical Factors on Strengthening of Steel Tire Cord", Wire Journal International, Dec. (1993), 50-61.
5. I. Ochiai et al., "Application of Hypereutectoid Steel for Development of High Strength Steel Wire", Testu-to-Hagane, 79(1993), 89-95.
6. T. Tarui et al., "Effect of Silicon on the Age Softening of High Carbon Steel Wire", I & SM, Sep.(1994), 25-30.
7. S. A. Al Salman, G. W. Lorimer and N. Ridley, "Partitioning of Silicon during Pearlite Growth in a Eutectoid Steel" Acta Met., 27(1979), 1391-1400.
8. N. Maruyama, R. Uemori and H. Morikawa, "Application of Field Emission - Analytical Electron Microscopy to the Study on Metal Materials ", Shinnittetsu Giho, 359(1996), 6-11.
9. T. Takahashi, T. Tarui and S. Konno, "Development of High Tensile Strength Wire of 180 kgf/mm^2 for Bridge Cable", Steel Construction Engineering, 1(1994), 119-126.

A QUARTER CENTURY OF STEEL CORD MANUFACTURE

STATE-OF -THE-ART TECHNOLOGY AND CRITICAL TOPICS FOR THE FUTURE

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Abstract

By the early 1970s, ingot casting was predominant for critical applications. In the 1980's continuous casting of large blooms became the metallurgical standard in a production route Blast Furnace - Basic Oxygen Furnace - ladle metallurgy. By the early 1990s, the steel industry began to consider a new compact, cost effective production route comprising Electric Arc Furnace steelmaking in line with direct billet casting. At the same time new developments, as higher strength grades, put a more stringent demand on wire rod quality. This paper gives a review of the changing situation, and highlights critical topics towards horizon 2000.

Metallurgy, Processing and Applications of Metal Wires
Edited by H. G. Paris and D. K. Kim
The Minerals, Metals & Materials Society, 1996

INTRODUCTION

The considerations developed in this paper intend to review the changing situation over a quarter century of steel cord manufacture. They go back to 1970, the year of introduction in the USA of steel-belted bias ply tires.[1] It is as well the year of commissioning of TrefilARBED's Bettembourg Plant.

THE STEEL CORD MARKET

For 1970 it was reported that 117,000 metric tons of steel cord were used worlwide, which represents approximately 12 % of 1995's consumption, Fig.1. The projection of some 1,221,000 tons by the year 2000, or 121 % of the 1995 reference, is based on various considerations, having in mind a thumb rule, stating that industrialized countries have a steel cord consumption of approximately 1 kg per annum and per inhabitant, and the fact that the biggest growth will come from developing Asian countries, representing a total population of more than 2 billions.

MANUFACTURING OF TIRE CORD QUALITY STEEL IN THE 1970'S

By the beginning 1970's the share of continuous casting in the worldwide steel production of 595 million tons was only some 5 %, to be compared to 76.4 % in 1995, Fig. 2. The USA are presently at 100%, and Japan, France and Germany at a round 95%.[2]

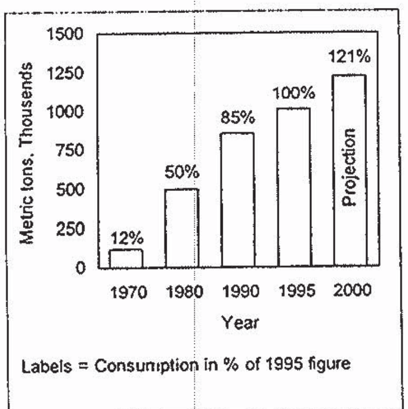

Fig. 1 - Evolution of worldwide steel cord consumption.

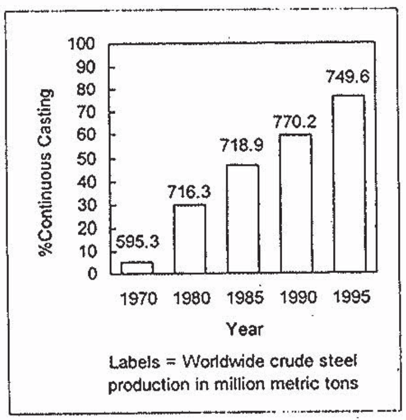

Fig. 2 - Share of continuous casting in world-wide crude steel production. [2]

Steelcord was exclusively produced by the conventional ingot casting technology. Big-end-up ingots were state of the art, because it allowed the segregation to be concentrated in the top of the ingot, a part which had to be scrapped or downgrades for less critical applications. The Stelmor technology was at it's beginning, and the steelcord wire rod of the early 1970's was to some extend produced on wire rod mills with an uncontrolled final cooling of compact coils. The rod's microstructure, and hence it's mechanical properties and drawability were poor and

inconsistent, Fig. 3. [3] Direct drawing of the wire rod, without intermediate patenting, to the plater-diameter was not possible. In some cases even the wire rod had to be patented.

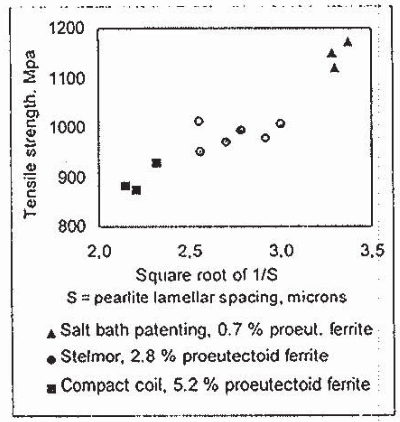

Fig. 3 - Effect of cooling on micro-structure and tensile strength of 0.67 %C wire rod 5.5 mm for steel cord applications. [3]

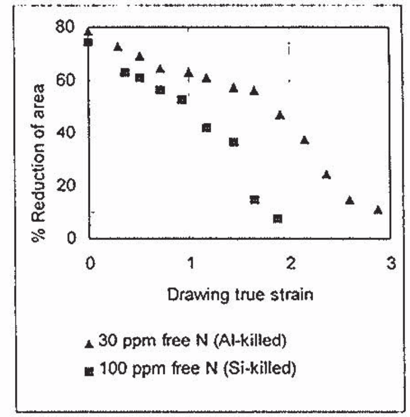

Fig. 4 - Effect of nitrogen on the evolution of ductility with drawing strain; low carbon steel, Al-killed, respectively Si-killed. [6]

SIGNIFICANT TIRE CORD QUALITY IMPROVEMENTS IN THE 1980'S

The second half of the 1980's decade saw the introduction and increasing use of 0.80 %C "High Tensile" tire cord grade in addition to the 0.70 %C "Normal Tensile" quality used exclusively in the 1970's. This evolution meant for the steel industry more stringent requirements on the wire rod metallurgical quality. The following table lists data from major wire rod suppliers to TrefilARBED, operating on the basis of BOF (Basic Oxygen Furnace) steelmaking and totalizing a share of 76 % of the world steel cord production.

Table I Year of Transition from Ingot Casting to Continuous Casting and from prior Art Wire Rod Cooling to Stelmor or equivalent Technology

Supplier	Year of transition ingot / continuous casting	Year of introduction of Stelmor or equivalent wire rod cooling technology
1	1980	1971
2	1981	1976 (rod mill 1); 1983 (rod mill 2)
3	1981	1973
4	1977	1968

Important developments have been made during the 1980's and consolidated in the beginning 90's in the fields of control of chemical composition by appropriate hot metal pretreatment and optimized BOF refining technology, ladle metallurgy, continuous casting technology, and wire rod rolling.

CHEMICAL COMPOSITION

PHOSPHORUS AND SULFUR. P is subject to intense microsegregations, with an enrichment factor of up to x 16 in segregation bands. It is furthermore an extremely potent agent for increasing martensitic hardenability in synergy with Mn-segregations.[4]. S, in synergy with P, significantly lowers the torsional ductility of the metal for %(P+S) levels > 0.020.[5] Analysing the (P+S) distribution of wire rod deliveries showed that our suppliers score ≤ 0.020 % (P+S).

NITROGEN plays a key role in aging phenomena with a detrimental effect on ductility, Fig. 4.[6] Dynamic and static strain aging are attributed to dislocation pinning by interstitial N, as well as by carbon in ferrite originating from cementite decomposition during drawing.[7][8] Strain aging thus adversely affects wire drawability and further processing to cord. The addition of boron and titanium as nitrogen fixing elements is not efficient without prior Al-deoxidation, a prohibitive operation in steel cord grades. As for P and S, a strict limitation of the N-content seems to be the most promising way to improve drawability and ductility properties of the wire. The distribution of the N-content for different suppliers and grades, Fig.5 shows that top qualities from BOF steelmaking do not exceed 40 respectively 30 ppm N. The grade from EAF steelmaking exhibits the highest N-values, with individual heats ranging up to 60 ppm N. The target of 50 ppm max or preferentially 30 ppm max N-content recommended by Lefever and Lombaerts [9] seems difficult for the Electric Arc Furnace (EAF) process route.

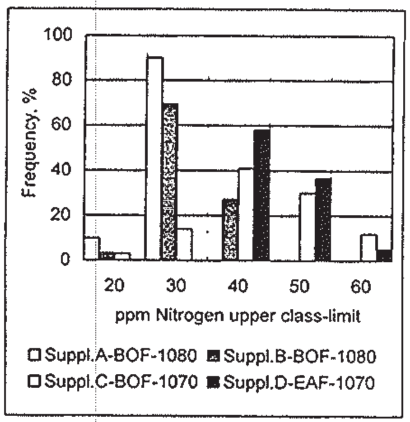

Fig. 5 - Nitrogen distribution for different suppliers of wire rod grades AISI 1080 and 1070.

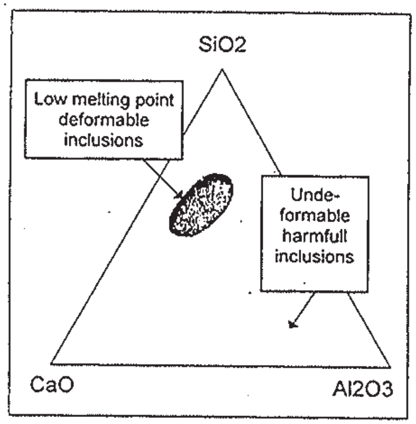

Fig. 6 - Ternary oxide system with range of deformable and undeformable inclusions. Schematic, do not scale.

LADLE METALLURGY

Ladle metallurgy includes fine trimming of chemical composition and superheat control. The latter is an important metallurgical and operational factor concerning control of centerline segregation and timing for sequence casting. Ladle metallurgy is in most cases performed in ladle furnaces; tundish plasma heaters are an alternative solution for superheat control. A preliminary condition to all operations is the prevention of BOF slag from pouring into the ladle. Various stoppage techniques have been developed. At the begining of the 80's decade it was generally believed that vacuum treatment of the liquid steel in the ladle would be beneficial with respect to cleanliness. There is no doubt that degassed steel has a lower volume of non-metallic inclusions. Finally metallurgists recognized that the type of residual non-metallic inclusions was of equal importance. [10]-[15] The new concept is schematically shown in a simplified ternary oxide system, Fig.6. Suitable slag flux treatments were developed in order to obtain inclusions with low melting points that can be deformed and reduced to a harmless size in the rolling and drawing steps. Vacuum degassing was found to be a potential source of problems by creating the thermodynamic conditions for the formation of alumina-rich inclusions.

CONTINUOUS CASTING

Casting of large size blooms is state-of-the-art technology for the top suppliers, table II. Other important features are: prevention of air ingress during teeming, use of large tundishes with appropriate shape for optimal inclusion upfloating, automatic tundish and mould level controls for optimal surface quality, submerged pouring with adequate casting powders, stable casting conditions.[16] The superior surface quality of wire rod from CC blooms, and the increased homogeneity of chemical composition in comparision with wire rod from the ingot route was soon established. Electromagnetic stirring in the mould, in the secondary cooling zone and at crater end has been applied for many years without solving the remaining problem of centerline segregation, which affects all CC products. Besides non-metallic inclusions, centerline segregation is a major cause of cup-cone type buncher breaks, mainly with eutectoid and hypereutectoid steel grades. The question concerning a suitable metallographic evaluation of centerline segregation and the resulting detrimental grain boundary cementite formation, in relation with bunching performance was the object of a recent report to the Commission of the European Communities.[17] A new improved evaluation chart taking into account the latest state-of-the-art was proposed. A real improvement was achieved with the implementation of soft reduction applied to the strand. According to our experience, cup-cone breaks are virtually non-existant with wire rods from top suppliers applying the aforementioned technology.

Table II Bloom Formats, by Order of Section Size
(Sb = Section of Bloom Sw = Section of 5.5 mm Wire Rod)

Caster No	Section size [mm x mm]	Section [mm^2]	Ratio Sb/Sw	Square Root of Sb/Sw
1	305x502	153 110	6 444	80.3
2	300x400	120 000	5 051	71.1
3	265x385	102 025	4 294	65.5
4	260x360	93 600	3 940	62.8
5	240x320	76 800	3 233	56.9
Billet Caster	155x155	24 025	1 011	31.8

WIRE ROD MILLS

Revamping of wire rod mills to modern standards has been achieved by major producers of tire cord grades, comprising the following items: Replacement of the pusher type reheating furnace by a walking beam furnace with automatic reheating process, allowing to achieve a better temperature distribution of the billets, and a reduced surface decarburization; improved roll pass design; use of tungsten carbide rolls in the prefinisher and the High Speed No Twist finishing block, assuring good surface quality and reduced dimensional tolerances; implementation of laser diameter control devices and eddycurrent surface inspection; automized precise temperature control over the length of rolling and before the laying head, an important factor in view of the formation of a regular scale suitable to mechanical descaling; replacement of the chain conveyor by a roller table conveyor, with steps and variable speed in the sections, eliminating the hot spot; increase of air blowing capacity, allowing cooling speeds up to 25 °C/s with optimal, flexible air distribution over the conveyor width to compensate for the greater density of material at the edges of the conveyorized coils. Cooling rate is an important factor in prevention of grain boundary cementite, especially for hypereutectoid steels.[18]

TRENDS IN THE LAST DECADE OF THE 20TH CENTURY

METALLURGICAL DEVELOPMENTS

The comparision, in table III, of steel cord with some other competing reinforcement materials [19] identifies the strength level, in addition to the high Young's modulus, as the strong point with further potential for development.

Table III Properties of some High-Strength Reinforcement Materials

Material	Tensile Strength [MPa]	Modulus [MPa]	Density [kg/m^3]	Fatigue Resistance
Nylon 66	990	5 600	1 140	Good
Polyester	1 150	13 400	1 380	Good
Aramid	2 760	58 000	1 440	Good
Normal Tensile Steel cord	2 700	208 000	7 800	Good
High Tensile Steel cord	3 250	208 000	7 800	Excellent

SUPER TENSILE AND ULTRA TENSILE STEEL CORD. Increased tensile strength of steel cord will play a major role in the weight reduction of tires and cars, having in mind that the corporate average fuel economy (CAFE) standards will be higher in the future. [1] Table IV lists classical and new steel cord grades designated according to the as drawn tensile strength at a filament diameter of 0.200 mm. The manufacture and total deformation data are those experienced by TrefilARBED Bettembourg.

Table IV Classical and new Steel Cord Grades

Steel cord grade	Typical TS-level [MPa]	Manufacture from wire rod grade	Deformation
Normal Tensile	2700	0.72 %C	low-medium
High Tensile	3250	0.82 %C	medium
Super Tensile	3650	0.82 %C	high
Ultra Tensile	3900 - 4000	0.92 %C + 0.2 %Cr	high

The 0.9 %C / Cr wire rod grade was originally designed by steel manufacturers to meet the requirements for Super Tensile steel cord. Wire drawers established soon that the ST-level could be achieved with the 0.8 %C grade, traditionally used for the manufacture of HT steel cord, and that the 0.9 %C + Cr grade had sufficient potential to attain the Ultra Tensile level with increased total deformation. Fig. 7 shows to this end the work hardening curves for different pearlitic wire rod grades. By combining steel grade and construction-type a large spectrum of breaking loads can be produced, Fig. 8.

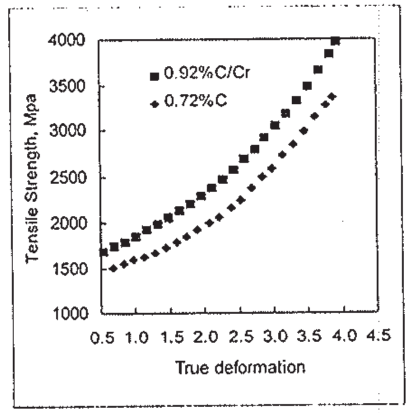

Fig. 7 - Effect of chemical composition on work hardening of pearlitic steel.

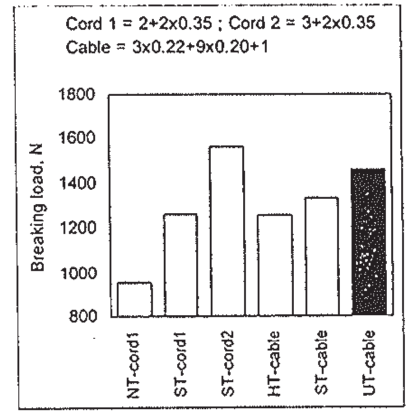

Fig. 8 - Breaking load of cords and cables from various T.S. level filaments.

With increasing tensile strength and true strain there is an increased tendency of unstable torsional properties. The bunching of filaments into cords becomes indeed problematic when the "delamination limit" is attained . Delamination is a longitudinal splitting of the wire in shear bands that occur in an early stage of the twisting process. [20][21] The final torsion breaks show a typical "delamination helix". The critical tensile strength level corresponding to the delamination limit decreases with increasing filament diameter. Triggering of delamination depends on the multiaxial stresses in the wire: residual stress from fine drawing, local stresses at stress raisers like surface defects or non-metallic inclusions, and process related stresses. Hence the delamination limit for a given diameter depends on a number of factors related to the metallurgical quality of the rod and the drawing and bunching process parameters.

In experiments involving factorial design with a number of drawing parameters as variables, Starinshak and co-workers [22] highlighted the beneficial effect of a double-die practice [23] on torsional ductility. Owing to the growing efficiency of computers, the simulation of complex deformation processes by finite element methods has become popular.[24] We have used ARBED's FEM-model of wire drawing [25] to analyse the aforementioned situation and found that a double-die drafting practice strongly reduces the residual stresses at the filament centre, as shown in Fig. 9. Owing to their effect on residual stresses, other technologies, like stress relieve heat treatments or straightening of the filaments are helpfull in prevention of delamination.[26] [15]

By using the appropriate combination of process parameters we achieved the production of delamination-free 0.200 mm UT filaments, as well as 0.35 mm ST filaments. Fig.10 illustrates that the torque-shear strain curve is smooth, with no sharp decrease of torque occuring when delamination is triggered. The corresponding fracture morphology is characterized by the absence of longitudinal splitting. Both criterions, curve aspect and fracture mode demonstrate the sound torsional behaviour, Fig. 11.

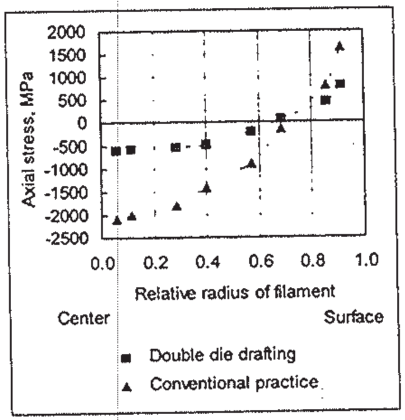

Fig. 9 - Effect of drafting practice on residual stress distribution. [25]

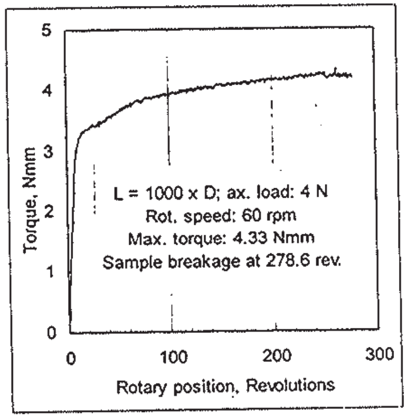

Fig. 10 - Torque-shear strain curve of a 0.200 mm UT filament

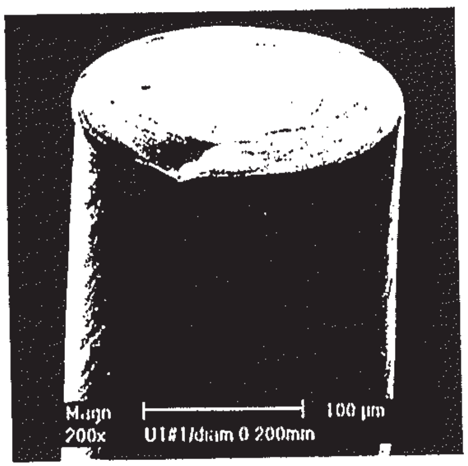

Fig. 11 - Torsion test fracture morphology of a 0.200 mm UT filament

PRODUCTION OF HT CORD FROM AISI 1070 STEEL GRADE SERVING AS A SUBSTITUTE FOR AISI 1080. The basic idea is to compensate the %C decrease by an increase of deformation, Fig. 8. Expected advantages are broadening of the wire rod suppliers periphery, and cost reductions, AISI 1070 being less expensive than 1080. The increasead entry diameter at fine drawing means improved productivity at the predrawing and plater operations. Possible disadvantages include decrease of die life, and increase of stranding break rate,

meaning a decrease of productivity. In a series of semi-industrial trials, Table V, the feasability could be demonstrated in terms of buncher production per break and product properties.

Table V Manufacture of a Cable 3x0.265+9x0.245 HT from Steel Grade 1070

	0.265 mm filament	0.245 mm filament
Plater diameter	1.70 mm	1.55 mm
Filament Tensile Strength	3182 MPa	3206 MPa
Cable Breaking Load	1798 N	
Specification on Br. L.	1810 ± 100 N	

TRENDS IN STEELMAKING

SHORT PRODUCTION ROUTE AND NEAR NET SHAPE CASTING. The leitmotiv of increasing cost-competitiveness does not change, but the response to it does, because of the evolutionary nature of developments pursued within the the economic framework dictated by the marketplace.
In 1989 NUCOR Steel became the trendsetter of a new era in flat steel products with the commissioning of its Compact Strip Production plant in Crawfordsville, Indiana / USA, followed in 1992 by the CSP-plant in Hickman, Arkansas. [27] Short production route and near net shape casting are the key elements for this thin slab production from Electric Arc Furnace (EAF) steelmaking. During the last two years ARBED, a world leader in structural shapes, replaced the conventional route Blast Furnace / Basic Oxygen Furnace / Ingot Casting by a shorter production route based on EAF steelmaking followed by Beam Blank Continuous Casting.
Although electric steel made up only 33 % of the total steel production of Western Europe in 1992, its importance is growing. [28] Faure [29] predicted a future share of some 60-65 %, including EAF and Multi-Energy-Furnace steelmaking. In the list of reasons for this development we have, among others, the ecological need for scrap recycling, the high flexibility of EAF, and new developments in plant engineering. In view of the current development to produce high grade steel products also on scrap basis in electrical steelmaking plants, sponge iron (DRI, direct reduced iron) has become an interesting charge material. It provides control of tramp elements like Cu, Ni, Cr, Sn, and a possibility of limiting the nitrogen content.[30] Solid sponge iron is produced in a direct reduction process of iron ores with gas or coal. Gas reduction has a dominant share, especially the Midrex process with some 64 % of the 20.6 million tons produced in 1992. [31]

TIRE CORD STEEL FROM A SHORT PRODUCTION ROUTE, combining either EAF or BOF steelmaking and direct billet casting is actually under development by various steelmakers. The charging materials in the EAF are high quality selected or internal scrap, liquid pig iron, DRI. The billet size varies from 120x120 to 155x155 mm, depending on the leading pass of the rod mill. Our experience with this type of wire rod is summarized in table VI.
The old problems, centerline segregation and non-metallic inclusions, which are actually mastered in the bloom casting technology, have reappeared with vigour. Intensive secondary cooling gives billet casters some potential of control of the centerline segregation. Concerning non-metallic inclusions and the need of reducing them to harmless size during rolling, the lower section of direct cast billets,compared to large bloom sizes, constitutes a definite

disadvantage. Furthermore the use of very small section sizes, making submerged nozzle casting with powder protection difficult, is questionable.
In the case of AISI 1080 grade for critical applications the short process route does not seem to meet the expectations in a near future. As concerns AISI 1070, there is some hope of short term progress. For both grades development work must be pursued.

Table VI Drawing and Bunching Plant Performance of Wire Rod from a Short Production Route with Direct Billet Casting

Steel Plant	Steel-making	Processed AISI Grade / plant performance	Comment
1	EAF-scrap-DRI	1070 / Poor	Centerline segregation ⇨ Cup-cone breaks Undeformable inclusions, up to 60 microns.
2	EAF-scrap-liquid pig iron	1070 / Poor	High concentration of tramp element Cr ⇨ martensite in the as patented state.
		1070 / Good	Selected scrap quality.
3	BOF	1070 / Poor	Centerline segregation ⇨ Cup-cone breaks.
4	BOF	1070 / Good	
		1080 / Good	
		1080 / Poor	Centerline segregation ⇨ Cup-cone breaks.

SUMMARY AND CONCLUSION

The present report was intended to show the changing situation in steelmaking and wiredrawing of tire cord grades. For critical applications the process route based on BOF steelmaking and bloom continuous casting was a question of strong debate at the beginning 1980's, but got soon established as state-of-the-art technology. Today a new compact, cost effective production route comprising Electric Arc Furnace steelmaking in line with direct billet casting is under development. As steel cord producer, situated half-way between steelmaking industry and tire plants, we are convinced that close partnership in both directions is a necessity. We are prepared to achieve our part of the job to maintain the steel cord's dominant position in the high strength reinforcement business of the 21st century.

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P.B.

Rod requirements for steel cord filaments

Jozef Lombaerts . . . features of the hot rolled high carbon rod

World crude steel production in 1992 was estimated at 690 million tonnes, less than 10% of this has been processed into wire rod. In this market, about 1 million tonnes of wire rod is annually transformed into steel cord. Definitely very low in tonnage, this quantity is very impressive in length and consequently a major market for manufacturing equipment.

The product

Steel cord is the vital reinforcement material of radial passenger car and truck tyres. The reinforcement consists of very fine cords of hard drawn steel filaments, Figure 1. The cords have a diameter of 0.5 mm up to 3 mm and are composed of an assembly of hard drawn steel filaments with a tensile strength of 2,500 N/mm^2 or more[1]. The filament size ranges from 0.15 mm up to 0.40 mm Ø.

In a radial, steel reinforced tyre, Figure 2, the main reinforcement areas are the breaker, supporting the road contact of the tread, and the carcass, which constitutes a flexible connection from bead to bead.

Passenger car tyres mainly have a carcass reinforcement of textile fibres and a breaker of steel cords. Truck tyres and off-the-road tyres basically have a structure where both breaker and carcass contain a steel cord reinforcement. By its nature of very small axial deformation, the cords in the carcass can only be present in a single layer configuration. Several layers can be present in the breaker to provide the necessary rigid shape of the tyre and driving stability.

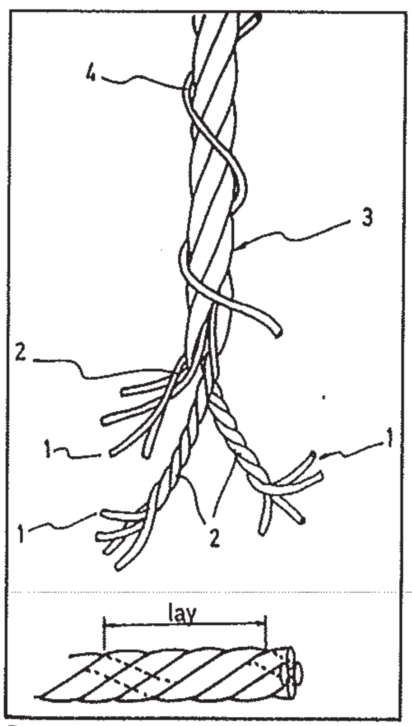

Fig 1 Steel cord components
1) Wire filament, 2) Strand, 3) Cord, 4) Wrap

Any increase in market share of steel cord will consequently influence the future of fine wire manufacturing equipment.

The feedstock

The technology of steel cord for tyres requires systematic dedication to the manufacturing process in all stages, beginning with extractive metallurgy and ending with the pay-off creel at the tyre plant.

This article is limited to the features of the hot rolled high carbon rod. The five major parameter families influencing the performance of the finished product are:

1. Chemical composition
2. Segregation
3. Cleanness or non-metallic inclusions
4. Surface condition
5. Macro- and micro-structure.

Each of them has specific targets to fulfil and will be handled here very briefly. A checklist is included in Table 1.

Steel manufacturing process

At present, the standard practice for manufacturing steel wire rod includes:

- blast furnace (BF) operation with selected ores
- basic oxygen furnace (BOF) with use of selected scrap

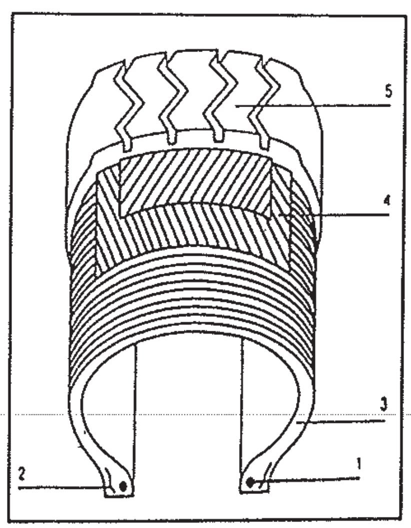

Fig 2 Main components of a tyre
1) Band, 2) Chafer, 3) Carcass, 4) Breaker, 5) Tread

- ladle refining sequence for chemistry and temperature adjustment
- continuous casting of blooms with immersed nozzle system
- downsizing of blooms into billets
- appropriate heat treatments to limit segregation and decarburisation
- low temperature rolling into rod with no-twist finishing
- controlled and intensive cooling after rolling for optimal metallographic structure
- tools and procedures for handling and transporting rod coils must avoid any contamination or mechanical damage.

Chemical composition

An analysis overview is listed in Table 2.

Carbon

The first specific requirement for the steel is a very close range of carbon content within the heat and between heats. The finished product will consequently also show a very uniform UTS. Carbon levels are 0.70 to 0.75% for regular tyre cord or 0.80 to 0.85% C for high tensile cord.

Secondary elements

Only manganese and silicon are alloyed in the steel to very precise levels and relate to the de-oxydation of the steel before casting. The levels are kept as constant as possible. Micro-alloyed grades also exist.

Residual elements

These are unwanted and remain in the steel as regular impurities. Very low targets are set for sulphur, phosphorous, nitrogen and oxygen. Metallic impurities can only be controlled by selection of ore, scrap and alloying additions.

Low levels of residual elements will allow a larger deformation in wire drawing. Aluminium is avoided because of its reaction into hard inclusions.

Segregation

Depends mainly on the casting process with attention paid to:

- overheat temperature
- stirring action in the mould or below the mould
- cooling speed and strand cooling programme
- additional physical interaction during final solidification ►

Table 1 Check-list on rod requirements for high carbon steel

ANALYSIS Carbon. **Alloying elements:** Manganese, Silicon, Aluminium **Non-metallic residuals:** Phosphorous, Sulphur, Nitrogen, Oxygen **Metallic residuals:** Copper, Chromium, Nickel, Tin Molybdenum, Cobalt.
PHYSICAL PROPERTIES Diameter, Out of roundness, Tensile strength, Reduction of area, Scale amount, Descalability.
METALLOGRAPHIC PROPERTIES Carbon segregation, secondary segregation (white bands). **Inclusions:** Number, type, max size. **Structure:** Average grain size, grain size regularity, occurrence of martensite, bainite, secondary cementite, coarse lamellar pearlite.
SURFACE Decarburisation, Cracks, Roughness, Rolled-in-scale, Scale structure, Scale thickness.

Segregations are mostly, but not only, related to an increased carbon content in the core of the product. For rod products, a set of metallographical reference pictures will allow a level rating. With increasing carbon content, the tendency to segregation also increases. Proper heat treatment of blooms and billets can eventually limit or reduce carbon segregation levels.

At present, effective systems are worked out to obtain very small segregation levels and for very high carbon levels. This will affect the performance in terms of maximum deformation or ductility.

Non-metallic inclusions

Non-metallic inclusions are a consequence of final metallurgical refining and of contact with any substance or refractory before casting[2]. Maximum cleanness is necessary for drawing the rod into tyre cord filaments. Undeformable inclusions of 20 μm or more will eventually cause breakage in wire drawing, especially for the finest filaments[3]. Finer inclusions will also have an effect on endurance if occurring at the surface.

In ladle refining, the steel mill will influence the inclusion composition by an appropriate slag treatment.

Surface condition

The requirements for surface condition include not only the rolling defects but also secondary features like roughness, scale structure, rolled-in-scale, surface decarburisation and mechanical damage. Surface defects can be generated in casting (pinholes) or during rolling operations.

A general decarburisation of more than 1.5% of the diameter will affect drawability in the more severe drawing conditions and will also affect endurance levels. Rolled-in-scale refers to the roughness of the rolls in some stands of the rolling line.

The scale itself has to be removed before cold wire drawing, but an improper cooling programme will generate decomposition of wustite into magnetite. The descaling action will therefore be less efficient and drawability will be affected.

Rolling cracks of more than 0.10 mm long are recorded in metallographical inspection and if the occurrence is frequent or the cracks severe, the material is considered unsuitable for fine filaments.

Mechanical damage in transport and handling is by far the most frequent cause of process interruptions in the fine wire drawing and cabling stages.

Appropriate coil protection is an absolute must to safeguard the surface quality.

Table 2 Chemical analysts targets

	Regular Tensile		High Tensile	
	Spec Value	Realistic Target	Spec Value	Realistic Target
% C Min	0.700	0.710	0.800	0.815
Max	0.750	0.740	0.850	0.835
% Mn Min	0.400	0.460	0.400	0.460
Max	0.600	0.550	0.600	0.540
% Si Min	0.150	0.180	0.150	0.180
Max	0.300	0.250	0.300	0.240
% P Max	0.025	0.015	0.020	0.012
% S Max	0.025	0.015	0.015	0.010
% Cu Max	0.080	0.060	0.040	0.040
% Cr Max	0.080	0.060	0.060	0.060
% Ni Max	0.100	0.050	0.040	0.040
% Sn Max	0.010	0.02	0.007	0.005
% Al Max	0.003	0.003	0.003	0.003
% N Max	0.008	0.006	0.006	0.005
% O* Max	—	0.0020	—	0.0020

*Informative values only

Macro- and Micro-structure

It is expected that the rod will have a uniform and consistent eutectoid structure after cooling. The occurrence of irregular grain size throughout the section, bainite, coarse lamellar pearlite, martensite or secondary cementite are considered negative indications for consistent processing.

The rod receivers' process

All these requirements must reach the level of acceptable practice to ensure optimum performance in further processing. A given combination of rod characteristics will not always provide the same performance in different process conditions of steel cord manufacture. The manufacturing methods and the equipment will have an influence.

A change to different machinery, operating speed, reduction values in individual dies, back pull or pretension values, torsional loading, etc, will also affect the critical level that generates incidents, ie fractures. A process route involving direct drawing practice will put more stress on segregation, surface condition and structure.

The finest filaments require higher cleanness, smoother surface and a lower level of residuals. The lower residual element levels obtained in the recent past did allow a shift to better performing products so that dynamic strain aging effects could remain under control. An improvement in the cooling of drawing equipment improves filament ductility. The process equipment also acts as an inspection device for every inch of the product.

The modern design of equipment is dedicated to high speed drawing of filaments having the highest ultimate tensile strength, levels of 3,900 N/mm^2 are already available and large-scale sourcing will be the big challenge in the near future.

Conclusion

Requirements of rod for steel cord are a reflection of performance targets for the finished product and for the tyre cord manufacturing process.

A consistently reliable service to the ultimate customer is only possible with an optimum combination between product, process and equipment.

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Meeting Quality Targets for Steel Wire Rod

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Steel wire tire cord is a product that places stringent demands on many aspects of steel quality. This article looks at the special emphasis that is placed on the sophisticated steelmaking and casting technology used to develop the necessary steel purity, cleanness, and internal and surface quality. The authors conclude that the existing and developing technology in producing steel wire cord is well equipped to satisfy the current and future demands of the tire industry.

In the review by Shemenski[1] of the introduction and development of steel as a reinforcing agent for pneumatic tires, it is noted that the original patent was taken out as long ago as 1854. However, the general use of steel wire in this role did not become significant until late in the 1930s, reflecting the need for improvements in steel quality and downstream processing, and reductions in manufacturing costs.

Steel wire reinforcement experiences an extremely demanding service environment. It is required to give a tire shape, size, stability, bruise resistance, durability and load carrying capacity. Basically, the finished wire must exhibit high standards of strength, ductility and resistance to both fatigue and corrosion.

The consumption of steel cord worldwide[1] was 100,000t in 1970, but by 1990 this figure had increased by a factor of 10. The projected consumption globally, in the year 2000, is 1,300,000t.

The amounts of steel used in the various types of tire can be summarised as follows:

- Passenger tire, 0.5-0.9kg.
- Light truck tire, 2.7-3.6kg.
- Truck/bus tire, 5.4-6.8kg.

Steel Reinforcement

Steel is used in three areas of a tire, namely bead, belt and, in the case only of truck and bus tires, the carcass. A typical automobile tire contains, by weight, 4.7% of bead wire and 8.9% of cord. The bead wire helps to hold the tire on the rim of the wheel. The cord consists of four structural components, namely the filament, the strand, and the cord, i.e. the assembly of strands, and the outer spiral.

Originally the cord was constructed by stranding. More recently, the cabling process was introduced, and now cords can also be produced by a single-stage operation, namely bunching.

A typical steel composition for basic tire cord is 0.70/0.75%C-0.2%Si-0.5%Mn. However, since the 1970s higher carbon grades have been developed.

The manufacturing process for the production of wire filaments for cord can be separated into three major areas; steelmaking and casting, rod rolling and wire drawing. Steelmaking and casting can be subdivided into:

- Primary (BOS) steelmaking.
- Secondary steelmaking.
- Bloom casting.
- Bloom rolling.
- Automatic inspection of billets.

The production of wire rod, typically with a diameter of 5.0-5.5mm from billets with a section size of, for example, 115mm involves the following stages:

- Reheating.
- Rough, intermediate and finish rolling.
- Coiling.
- Post-rolling controlled cooling.
- Coil reform and compaction.

The stages of wire production can be summarised as follows:

- Coarse direct drawing reduction of 66-78% R of A.
- Lead patenting.
- Intermediate drawing reduction of 76-91% R of A.
- Final patenting.
- Brass plating.
- Wet Drawing Reduction of 60-96% R of A.

The diameter of the final filament is in the range 0.1 5-0.35mm.

Performance Criteria

To a large extent the performance criteria for steel cord manufacture involve the avoidance of wire failures during (final) drawing, stranding or service. The finished wire cord must also exhibit sufficient strength, and have a high enough modulus, to impart the required degree of stiffness to the tire.

The level of strength exhibited by cord can be used as a classification system, as indicated by the data[2,3] in Table 1.

A reliable guide to the material's resistance to failure is given by the levels of tensile and torsional ductility in the as-drawn wire. However, the degree of ductility is influenced by the level of strength, and this situation must be taken into account when considering the performance of a given grade of cord. An important phenomenon in this context is the change from good to bad torsion behaviour, i.e. the onset of delamination, that occurs with a change in filament size and strength. Quantitative examples are shown in Table 2.

Work by Yamada et[4] al has shown that the number of wire breaks during the manufacture of 0.8%C cord with 0.25mm filaments increased substantially once a strength of ~3200 N/mm² was exceeded.

The relationship between strength and fatigue limit is complex since, for example, this is affected by the diameter of filament used to construct the cord. Another aspect of the effect of strength on fatigue limit is illustrated in Table 3.

This shows that inclusion content becomes a more dominant cause of fatigue failures than surface defects as the strength is raised and the filament diameter becomes smaller.

Table 1: Classification system for cord according to strength

Grade	T.S. N/mm² for Filament Diameter, mm 0.175	0.20	0.30
Normal Tensile	2900	2850	2600
High Tensile	3500	3350	3000

Table 2: Effect of filament diameter and strength on tendency to delaminate in torsion test

Filament Diameter mm	Max T.S. N/mm² Before Start of Delamination
0.20	3600
0.30	3350

Table 3: Dependence of fatigue properties on filament strength, diameter and steel quality

Fatigue Fracture Site	Percentage Failures According to Filament Type		
	0.22mm 3200 N/mm²	0.25mm 3000 N/mm²	0.38mm 3000 N/mm²
Inclusions	83	57	12
Surface Defects	12	27	71
Unknown	5	17	17

Steel Quality Requirements

Clearly the manufacture of tire wires represents a very considerable and special set of demands on steel quality, somewhat different from those of more familiar steels encountered in buildings and construction. In particular, there are special requirements in respect of steel purity, steel cleanness, internal, and surface quality.

Steel Purity

This term is used to describe the content of residual 'tramp' elements in steel, i.e. those that are not added deliberately but instead arise as a consequence of the manufacturing process. Control of the levels of the tramp element content is widely believed to be necessary in high carbon wire steels, in order to promote good drawability, consistent heat-treatment response, and to ensure adequate final ductility[5]. The extremely high strains involved in production of tire wires (e.g. $\Sigma = 2.3$, RA = 90%) makes the issue of steel purity particularly critical, and almost all tire cord steel is manufactured in steel processes which employ primary iron as the starting material, as distinct from scrap melting (as in electric arc steelmaking).

A comparison is shown in Table 4 which indicates the low levels of tramp elements that can be achieved in Basic Oxygen Steelmaking, where blast furnace iron is the primary starting material.

In addition to control of the metallic tramp elements, low levels of P, S and N are also required to promote good torsion properties and ductility in the finished product[3] Low nitrogen contents are particularly important to limit dynamic strain-ageing which reduces ductility.

Strain-ageing

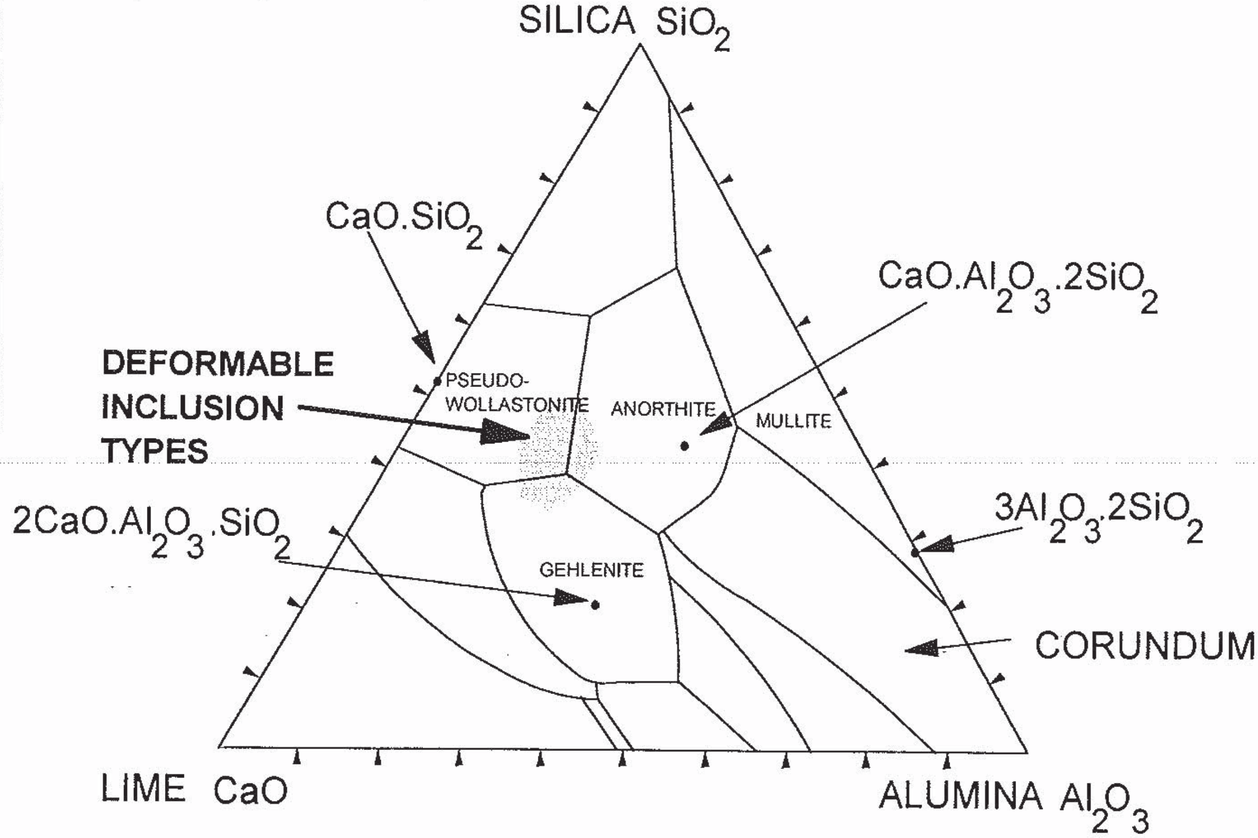
All steelmaking processes generate quantities of non-metallic inclusions in steel, and indeed it has been estimated[6] that even very pure steels may contain some 10^{12} small particles of oxide and sulphide inclusions per tonne of steel.

"Work by Yamada et al has shown that the number of wire breaks during the manufacture of 0.8%C cord with 0.25mm filaments increased substantially, once a strength of ~3200N/mm² was exceeded"

Table 4: Typical residual tramp element contents in steel (wt%) Sum1 = Cr + Cu + Mo + Ni + Sn

Steel	Cr	Mo	Ni	As	Co	Cu	Sn	Sum 1	P	S	P+S	N
Proposed General[5] Rod Specification	≤0.08	≤0.02	≤0.12			≤0.08	≤0.025	≤0.025				
Typical Tyre Cord Specification	≤0.06		≤0.06	≤0.30		≤0.06			≤0.020	≤0.020	≤0.030	≤0.007
Typical Electric Arc Steel (Scrap melting)	0.07	0.02	0.06	0.016	0.015	0.08	0.009	0.239				
Scunthorpe Works BOS Steel, Typical Tyre Wire Steel	0.022	0.002	0.022	0.003	0.002	0.015	0.002	0.063	0.009	0.005	0.015	0.003

Figure 1: Ternary section showing favoured inclusion species



Control of steel cleanness is a key feature for high quality high carbon wire steels. This is particularly so in tire wires where the very fine wires may approach the size of typical inclusions in ordinarily clean high carbon steels, engendering fractures if this occurs because of the local lack of ductility near the inclusions.

Even when wire breaks are not caused, deleterious effects can still occur, since inclusions near the wire surface may encourage fracture during fatigue, resulting in a restriction in tire life[2]

The population of non-metallic inclusions in tire wire steels is frequently divided into classes of deformable and non-deformable particles. The former, which include manganese sulphide and oxidic silicates, are able to deform during both hot-rolling and to a degree during cold-drawing of the steel, and are less likely to cause fractures than the non-deformable types. The latter include alumina (Al_2O_3) and mixed oxide species in which there is a high concentration of aluminium. Most oxidic inclusions in steels belong to the CaO (MnO) - SiO_2-Al_2O_3 systems, and the steelmaker must control processes to promote the formation of spessartite and pseudo-wollastonite which are deformable mixed oxides in these systems.

The content of non-metallic inclusions in clean steels is very difficult to estimate in a satisfactory quantitative manner, because of the very small size, and low numbers, of the particles. Nevertheless, specifications have been evolved which require that microscopic counts of non-deformable particles are controlled to below limiting values (e.g. French standard NFA 04-107), which when achieved provides the wire drawer with steels that his practical experience shows can be converted successfully into tire cord. Specific companies have developed more detailed inclusions specifications.

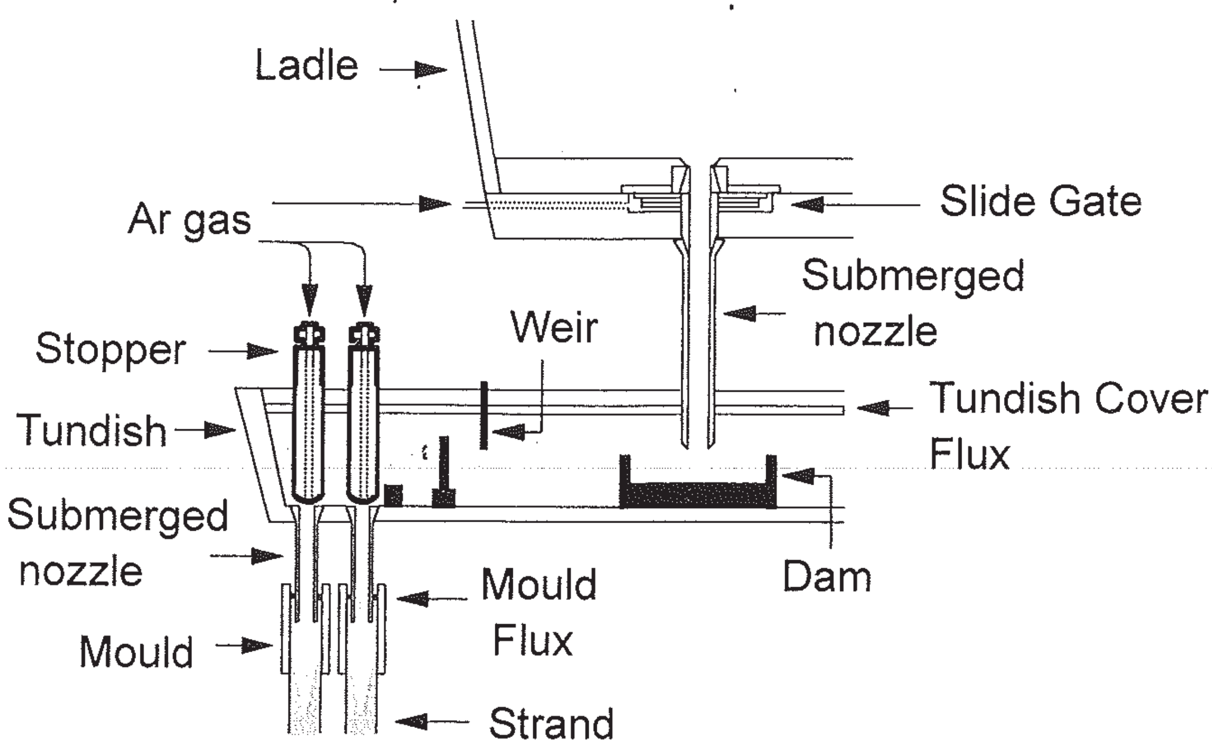
Steelmakers involved in tire wire manufacture must employ sophisticated analysis techniques (e.g. EPMA, SIMS) to characterise inclusion species, thereby to understand the complex process details which control steel cleanness and to provide the basis for improvement (e.g. Figure 1).

Internal Quality

Apart from steel cleanness, the principal feature of internal quality is the level of segregation of major elements, notably carbon. Segregation is manifest in the form of axial inhomogeneity, whereby typically a high concentration of carbon might be found at the axis of the cast object. This is a result of the solidification process in which the earliest freezing of relatively pure material pushes a reservoir of relatively impure liquid ahead of the solidification front, which is then the last material to solidify near the central axis. The segregation varies in intensity, according to casting conditions, in both the radial direction and along the longitudinal dimension of the casting. If segregation is excessively intense, involving the elements C, Mn, P, there is a risk of forming small particles of martensite in the structure. Such particles are undeformable during wire drawing, and promote fractures and poor properties in finished wire.

Segregation and its control are dependent on the process route details, particularly the casting temperature,

Figure 2: Sketch of bloom caster shrouds and tundish systems



and the characteristics of the casting process or machine.

Surface Quality

Surface quality comprises both the characteristics of any surface defects, and the degree of decarburisation, that may be generated during the process and carried forward to the tire wire products.

Surface inspection and rectification techniques may be capable of reducing or eliminating any defects that have formed during earlier stages of manufacture, and such techniques are usually an important part of billet production. Economic forces, however, require that processes of continuous casting, reheating, and rolling, are optimised to minimise defectives so that inspection and rectification can proceed at minimum cost.

Undetected surface defects may progress to the rod rolling process, and from there to wire drawing, where excessive defects would be expected to produce fractures. Even with excellent billet surface quality and minimum decarburisation, the rod rolling processes can create new levels of defects, so that the billet and rod processes must be controlled carefully to provide satisfactory quality.

Decarburisation, if excessive, will prevent the finished wires from achieving adequate fatigue endurance, thereby reducing the life of tires.

Manufacture of Tire Wire Steels at BS, Scunthorpe

The manufacturing processes at British Steel Scunthorpe Works closely follow the requirements outlined in the foregoing.

Iron is manufactured in blast furnaces, using sintered foreign ores, and coke produced from imported high quality coals, producing iron of low residual tramp element concentrations (Table 4).

The liquid iron is transferred to the Basic Oxygen Steel (BOS) plant, where it is desulphurised by a two-stage process of soda ash additions and deep injection of magnesium-based compounds. The sulphur content is reduced from about 0.06% in the hot iron to as low as 0.005% for premium quality tire wire steels.

The charge material to the 300t BOS vessels has a typical composition of 4.5% C, 0.5% Si, 0.3% Mn, 0.09% P, 0.005% S. Some (about 20%) steelworks scrap ("virgin" scrap of low tramp element content) is added to act as a coolant, and primary steelmaking proceeds employing an optimum refining path determined by computer models from audiometric and decarburisation rate measurements. The oxygen blow produces conditions which promote good carbon and phosphorus removal, the latter being absorbed into the refining slag which is formed by lime and other flux additions. The main alloying (C, Mn) and deoxidation (Si) steps are conducted at tap in the ladle, prior to secondary steelmaking processes.

The steel proceeding to secondary processes thus contains low levels of the tramp elements, and of S, but a key feature for secondary steelmaking is phosphorus control which requires the

> "Economic forces, however, require that processes of continuous casting, reheating and rolling, are optimised to minimise defectives so that inspection and rectification can proceed at minimum cost"

separation of the phosphorus-rich primary slag from the liquid steel. This is effected by a combination of features: detailed attention to taphole maintenance, slag detection during tapping by the use of electromagnetic sensors, and rapid backward tilting on detection, and by the use of slag dart stoppers which float at the slag-metal interface and block the taphole before issue of slag during pouring.

Secondary steelmaking processes are employed to condition the steel in terms of composition, temperature, and purity, prior to casting.

At Scunthorpe Works, the first process is a simple Ar-bubbling process, which assists in temperature and compositional homogenisation, and encourages refining reactions with the active synthetic slag which is created on the top of the ladle in order to remove phosphorus and act as a sink for inclusions.

The refining processes are continued at the RH vacuum degasser, where melt circulation encourages inclusion agglomeration, flotation, and removal to produce high quality clean steel. Moreover, during the degassing cycle, sampling and chemical analysis are conducted, followed by secondary alloying and composition adjustment for precise control to target chemical specifications.

Vacuum degassing also removes nitrogen from the low sulphur steel, with levels as low as 30-40 ppm being achievable.

Casting is conducted in a 4 Strand Bloom Caster. The large section size (750 x 355mm) enables a secure full-shrouding system to be employed, with total enclosure by means of submerged nozzles between ladle and tundish, and tundish and moulds. The total shrouding system is vital to prevent reoxidation and nitrogen absorption during casting, enabling the production of low nitrogen, clean steels (see Figure 2).

The extremely large section size is also important in respect of segregation: with good control of casting temperature and the slow freezing rates in the large blooms, central carbon segregation is limited to a small diffuse zone which is unlikely to cause generation of martensite, and which is comparable to the best material available.

The large blooms require a relatively long reheating cycle prior to rolling to billets in a modern Bloom and Billet Mill. The cycle is carefully controlled to ensure minimum decarburisation (e.g. minimum time at soaking temperatures), but does provide a homogenisation stage which complements the low segregation characteristics of the Bloom Caster by allowing diffusion of even minor segregates. Rolling involves two reversing breakdown stands and a continuous finishing train of up to 10 stands in alternate vertical-horizontal configuration. The finished billet sizes for rod mills are typically 115mm and 140mm square, and up to two tonnes in mass.

The mill process routes are designed to build-in quality at all stages, but increasingly rod rollers demand final inspection and rectification of their billets. This demand is now being met by a major new inspection and rectification line, which includes shot blasting, surface inspection (Elkem 'Therm-o-matic'), internal inspection by an ultrasonic system ('Sonomatic'), and machine grinders.

The 'Therm-o-matic' device detects heat emission peaks from any defects when the billet is excited by an induced HF current. Four IR cameras scan the full billet surface, sending detection results to the machine computer which supervises paint sprays to mark any defects which exceed specified depth and length thresholds. The marks are used to direct grinding operations to rectify billets as necessary at one of our machine grinders.

> "Steelmakers involved in tire wire manufacture must employ sophisticated analysis techniques (e.g. EPMA, SIMS) to characterise inclusion species, thereby to understand the complex process details which control steel cleanness and to provide the basis for improvement"

The ultrasonic machine by 'Sonomatic' is an immersion system based on the pulse-echo technique. An array of up to 32 probes send ultrasonic pulses into the billet and subsequently detect the reflected signals which are sorted electronically into 'good' and 'defect' echoes. Again the results are passed to a machine computer which controls paint sprays to mark any defective parts of billets for removal.

A process control computer supervises the whole conditioning line, and records very detailed quality information for product development purposes.

Rod Rolling

Important metallurgical characteristics affected by the rod rolling operation are surface quality, descalability and microstructure. Surface quality involves three features:

- Control of the size and number of defects.
- Avoidance of embedment of carbide particles from the rolling discs.
- Elimination of sources of mechanical damage, during handling and transport.

Mechanical damage is the most frequent cause of problems during fine wire drawing and cabling[7]. The first two items listed above are both satisfied by choosing a rolling window early in the life of the discs and the roughing/intermediate rolls. The use of in-line monitoring of stock size/shape and defect detection are essential aspects of rolling practice.

Descalability refers to the ease and efficiency of removing scale formed mainly during the early stages of post-rolling cooling. Removal can be affected chemically or mechanically, and the latter is becoming the more popular practice. Incomplete removal of scale will have an adverse effect on drawability[8].

For mechanical descaling it is necessary to develop a scale which results in a high residual shear stress at the interface with the steel surface, to encourage a peeling action. This is favoured by a relatively thick layer of crack-free scale, where the innermost layer, namely wustite, has not transformed to magnetite.

The process variable which has the biggest effect on the nature of the scale is the temperature at which the rod is laid on to the forced air cooling conveyor. A typical temperature would be 900-950°C, and this would be expected[8] to produce 0.5-0.7% by weight of scale. Billet reheating temperature and forced air cooling rate are only minor variables in this respect.

It is important that the surface of the descaled rod has a suitable degree of roughness, in order to optimise the efficiency of the wire drawing lubricant.

The nature of the pearlitic microstructure in the finished wire is

Table 5: Targets for the future strength of cord filaments

Filament Diameter mm	T.S. N/mm²	
	Super Tensile	Ultra Tensile
0.20	3600	+3900
0.30	3350	+3600

determined to a large extent by the conditions of the patenting operation. However, the microstructure of the as-rolled rod must be suitable to withstand the initial, direct drawing reduction without sustaining damage.

It is well established that the most beneficial morphology consists of closely spaced thin laths of cementite, without the degeneration of lath continuity that indicates the start of a change to a bainitic microstructure. This microstructural requirement is achieved by operating with a reasonably high rod laying temperature, compatible with mechanical descaling requirements, so as to form coarse prior-austenite grains which exhibit good pearlitic hardenability. This is followed by the application of a reasonably fast forced air cooling rate during the transformation to pearlite.

There is some evidence that the formation of a fine pearlite nodule, i.e. grain size, is beneficial to ductility[9]. However, this would require the use of a low laying temperature to produce fine austenite grains, which would not be compatible with the needs for mechanical descability and good pearlite hardenability.

As well as the importance of the particular morphology of the pearlite, it is important to create a uniform microstructure. Consequently, the distribution of forced air to the rod on the conveyor is designed to offset the effect of differences in packing density within the helically arranged coil, so as to provide reasonably uniform around-ring cooling.

Future Developments

The main theme for the future development of tire cord is the production of even higher levels of Strength[1] This is needed in order to reduce the weight of tires and improve fuel economy. Published goals for strength[2] are shown in Table 5.

The expectation is that within the next decade strengths of at least 4000 N/mm² may be available[1]

Basically, there are three sources of extra strength, as follows:

- An increase in the strength of patented wire.
- An increase in the rate of work hardening during wire drawing.
- An increase in the final wire drawing reduction.

With regard to the patenting treatment, it is unlikely that there is scope for a further significant improvement in technique. However, there is opportunity for raising strength by increasing the carbon content still further, and a content of ~ 0.9% has been mentioned[10]. Also, alloying additions of agents such as silicon and chromium should be effective.

As a consequence of an increase in strength of the patented wire there is likely to be a corresponding increase in the work hardening rate in drawing.

Gaining extra strength by increasing the magnitude of the drawing reduction will place severe demands on the standard of wire rod quality. Of special importance are steel purity in terms of phosphorus, sulphur, oxygen and nitrogen contents, cleanness and surface quality. The continuing improvement of modern steelmaking/casting and rod rolling technology should bring these targets within reach.

Some wire drawers are now considering the feasibility of eliminating the intermediate lead patenting treatment. This will require especially high standards of as-rolled microstructure and other aspects of quality.

Another topic of cord development is improved corrosion resistance. Although it is possible that this might be achieved by changes to steel composition, this must not interfere with the surface chemistry requirements for wire plating. A possibly more effective approach would be by modification of tire design. Avoidance of moisture ingress would be extremely beneficial for the fatigue limit[4].

Summary

The technical nature of steel tire wire for tire reinforcement, performance criteria, and the various stages in its manufacture have been described. It has been demonstrated that tire cord is a product that places stringent demands on many aspects of steel quality. Achievement of the necessary quality standards is vitally dependent upon strict controls being exercised over every one of the numerous stages of production in the total supply chain.

Special emphasis has been placed on the sophisticated steelmaking and casting technology used to develop the necessary steel purity, cleanness, and internal and surface quality. The rod roller then has the responsibility for maintaining every aspect of surface quality and controlling the post-rolling cooling conditions, to provide feedstock that is fully compatible with the wire drawer's processing technology and performance criteria.

The indications are that the existing, and developing, technology is well equipped to satisfy the current and future demands for steel cord for tires.

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Control of strengthening mechanisms in the manufacture of steel tire cord

Controlling the multiple elements that can affect the manufacturing process, from rod procurement to temperature control, is essential to quality and cost-effective production.

By Thomas W. Tyl

Tire cord is an essential product and controlling its strength properties in an efficient and cost-effective manner is vital to companies that produce it.

Although the term "strength" normally refers to load per unit area, cable strength is commonly referred to in terms of breaking load; cable effective cross sectional area is set once the construction is determined. For this article, breaking load and strength will be used synonymously without regard to cross sectional area. Cable breaking strength is the sum of all filament strengths multiplied by a cabling efficiency factor that in theory never changes for a given construction and twisting machine setup. In reality, other manufacturing factors can significantly affect apparent cabling efficiency.

Filament strength should be a control point for steel tire cord manufacture. It should be maintained within a specified range determined from cable construction and strength requirements. Failure to control filament strength can result in out-of-specification cable strength. Inadequate control of filament strength can result in wet drawing deficiencies and subsequent twisting performance issues. Too high a filament strength can result in elevated die wear and breakage and brittle filament during twisting while too low a filament strength can result in twist control issues. These concerns result in reduced filament and cable productivity, partially filled fine drawing take-up spools, high wet lubricant consumption and elevated fine drawing filament and cable waste.

Filament strength issues can be partially relieved by countermeasures unrelated to the root cause, such as increased lubricant consumption to help improve fine drawing performance. These relief measures can greatly increase manufacturing costs as well as maintenance costs associated with fine patenting and plating and wet drawing lubrication, die and sludge levels.

From an engineering, manufacturing, product uniformity, material waste and resulting financial standpoint, the advantages of tightly controlled filament strength far outweigh the ramifications of no or partial control.

Steel rod: strength variations

Unintentional steel manufacturing variations, including alloying and other strengthening mechanisms can result in strength disparities of up to 15 Newtons for 0.20 mm high tensile filament.

It is well known that steel composition changes tensile strength after patenting and work hardening rates during fine drawing. Steel rod composition affects filament strength by carbide strengthening in cementite, solid solution strengthening in ferrite and austenitic grain refinement during austenization. Tight composition control can drive up the cost of wire rod, the most expensive raw material. In addition to reasonable rod composition control through wire rod specifications, the carbon equivalent can be used to schedule rod delivery with the intent of minimizing changes in filament strength related to rod chemistry. Properly scheduling rod into the manufacturing plant can result in incremental changes in filament strength that are easily compensated for by changes in patenting conditions. Equivalent compositions can be measured by the carbon equivalent (CEQ) which relates to tensile strength and work hardening rates. CEQ can be an indicator of furnace and soaking conditions required to maintain stable filament tensile strengths.

There are many equations for CEQ, three of which are listed in Table 1. The elements listed in Table 1 represent percent by weight of each element in rod. The CEQ equations yield results listed in Table 1 for the listed rod chemistry.

Selection of an appropriate CEQ equation, which may not be included in Table 1, should be based upon the types and manufacturing methods of steel processed and the resulting filament breaking loads. Three examples will be considered.

Tire cord plant (A) consumes rod from a single rod manufacturer. The manufacturer uses conventional blast furnace technology to produce steel from iron ore and coke. Iron ore is supplied from one mine that has consistent residual elements or is blended from several mines resulting in consistent residual levels. Review of mill certification reports reveals that with the

%C	%Mn	%Si	%Ni	%Cu	%Cr	%Mo	%V
0.73	0.5	0.18	0.03	0.01	0.04	0.01	0.001
1. CEQ = C+(Mn+Si)/6+((Ni+Cu)/15+(Cr+Mo+V)/5							0.856
2. CEQ = C+Mn/6+Si/24+Ni/40+Cr/5+Mo/4+V/14							0.832
3. CEQ = C + Mn/5							0.830

Table 1. Carbon equivalency.

exception of carbon all elements are fixed, not varying from heat to heat. In this case the CEQ equation is irrelevant since carbon alone is variable; rod should be scheduled based upon the carbon content alone.

Tire cord plant (B) consumes rod from three rod suppliers. Steel rod manufacturers use conventional blast furnaces. Two suppliers consume iron ore blended from several mines resulting in consistent residuals. However, residuals levels between the two suppliers differ. The third supplier consumes ore supplied from a company-owned mine also resulting in consistent residuals. Residual element levels differ from each of the first two suppliers. Review of mill certification reports reveals suppliers are self consistent but residuals differ among suppliers. In this case a CEQ equation should be used to properly patent material conjointly from the three suppliers. Rod should be scheduled based upon the CEQ and the rod supplier.

Tire cord plant (C) consumes rod from a single rod manufacturer. The rod manufacturer uses direct reduced iron (DRI) and scrap steel in an electric melt shop. Scrap is meticulously blended and sorted to help ensure consistency. Review of mill certification reports reveals that all elements, carbon and residuals, vary significantly during a one year period. In this case a CEQ equation should be used since heats can contain differing residual levels; rod should be scheduled based upon the appropriate CEQ alone.

Other rod mechanisms. Mechanisms unaccounted for by CEQ can affect filament strength, for example elements present in rod but not routinely assessed. The most common are the five interstitials, strong carbide formers, grain growth inhibitors and unexpected traces of elements normally not associated with alloying such as arsenic. Rudiments of steel making also affect filament strength. Inclusion control techniques that leave a fine dispersion of inclusions at austenite grain boundaries can dramatically affect filament strength levels. Carbon and manganese segregation can change filament strength by generating rod with two plated tensile strengths and work hardening rates, core and outer. Rod decarburization can affect filament strength since decarburization can track through the entire manufacturing process, sometimes passing unnoticed as proeutectoid ferrite after final patenting. Countermeasures can be implemented for each case listed to help relieve impact of rod on differences in filament strength.

Steel rod: strength variations

Strength benefit. Tire manufacturers are pushing today's steel tire cord market toward higher strength cable, the advantage of which is reduced tire weight. Tire weight reductions result from lower cable linear density at higher strength levels and increased rivet during calendaring. Tire manufacturers commonly save more weight in rubber reduction than steel savings when moving to higher strength cable as synergistic savings associated with increased cable strength are significant.

Strengthening methods. A general rule for steel tire cord manufacture is that the manufacturing process becomes more sensitive to process changes as alloy content increases; patenting conditions must be more tightly controlled for higher alloy content steels. Significant strength increases can be realized through increased drawing strains rather than increased alloy content. Many tire cord manufacturers intentionally limit alloying, depending on increased strain for higher strength. This yields in-process product rationalization resulting in leaner manufacturing. Relying on greater total reduction to produce high strength filament strains wet drawing lubrication and die systems. Eventually steel alloys must be used to attain higher filament strength.

Alloying elements commonly added are carbon, silicon, chromium, manganese and boron. The most potent of these are the strong carbide formers or strengtheners which act to fortify cementite plates in fine pearlitic microstructures. Issues discussed in previous sections should be rationalized since differences in filament strength are magnified with alloying. This is notable for issues related to steel making.

Tyl

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Rod breakdown dry drawing

Small effects. It is a misconception that properly controlled rod breakdown drawing affects filament breaking strength. Rod breakdown drawing differs from direct drawing in that rod breakdown requires two additional processing steps prior to fine patenting and plating, namely intermediate patenting and secondary dry drawing. These two steps effectively reset microstructure and material and process related properties like strength and diameter. Properly controlled rod breakdown processes have a negligible effect on filament strength other than drawing-induced defects like internal bursting, excessive strain aging and surface defects.

Intermediate patenting

Complete Decarburization. Intermediate patenting impact on filament strength frequently involves decarburization. In the patenting furnace, high wire temperatures increase the driving force for diffusion of carbon. At the wire surface three reactions can occur under precise conditions: oxidation of iron; reactions between carbon water vapor and other gases; and reduction of scale. Total carbon depletion from the wire surface is termed complete decarburization; fractional carbon depletion results in a thin carbon-poor layer sometimes including proeutectoid ferrite along grain boundaries near the wire's surface and is termed partial decarburization. Complete decarburization is easily identifiable with standard etching or other techniques.

Partial Decarburization. Partial decarburization is more difficult to identify and commonly goes unnoticed. However, resulting carbon-poor regions can follow wire through the steel cord process resulting in filament strength variation.

Consider a 1080 steel with a thin carbon-poor layer at the wire surface after intermediate patenting. To go unnoticed during normal laboratory testing the composition of the carbon-poor layer could be as low as 0.70 w/o carbon, significantly less than a eutectoid steel. When the surface concentration falls below eutectoid, proeutectoid ferrite may or may not be observable depending upon cooling rate in soaking. During subsequent dry drawing the thin carbon poor layer is elongated and reduced in thickness, further hampering identification. During final austenization carbon diffuses from the wire's center toward lower concentrations at the wire surface. In the case of complete diffusion the carbon concentration difference is eliminated resulting in consistent chemistry throughout the wire albeit at a lower carbon content than listed on the mill certificate. When partial diffusion occurs during final austenization a thin carbon-poor surface layer remains.

Irrespective of decarburization magnitude, filament strength at true strains designed for 1080 steel will be significantly lower. For example a standard 0.20 mm high tensile filament can have a breaking load two to ten Newtons lower than target.

Another influence of intermediate patenting on filament strength involves surface damage, generally mechanical damage, although the surface can also be damaged by excessive furnace scaling. These defects are largely eliminated during subsequent processing.

Secondary/direct dry drawing

Hidden effects. Calculation of true strain versus filament strength can determine the effect of final dry drawn diameter on 0.20 mm high carbon filament strength. This yields an apparent 0.5 Newton filament strength variance for a diameter range of 20 microns. This paper calculation does not consider effects of dry drawn diameter on patented properties. The limiting parameter for heat transfer during patenting is heat transfer from the furnace through the wire surface, which is why the simple DV (Diameter times Velocity) calculation works: it is proportional to the surface area of wire moving through the furnace.

Consider the termini of a nominal 1.20 mm final dry drawn product with a 20 micron growth range patented at a single speed. Table 2 shows the final patenting DV difference is 1.1 m-mm/min. The equivalence speed, or the speed at which the DVs for the two diameters are equivalent, differs by nearly one meter per minute. This difference relates the difference in surface area to the heat transfer rate between furnace and wire. The surface area to volume ratio is relatively large (>3.0), meaning that there is ample surface area to heat the mass of material in the wire's interior. Differences in equivalence speed affect filament strength by as much as five Newtons.

Consider also the termini of a nominal 2.00 mm final dry drawn product with a 20 micron diameter growth range patented at a single speed. The larger wires require significantly more heat to produce even heating and the speed of heat transfer is again limited by the heat transfer rate through the wire's surface. Table 2 shows that the difference in equivalence speed is 0.3 meters per minute, but the surface area to volume ratio is small (~2.0) meaning that even relatively small differences in speed influences through heating. Differences in wire volume related to wire diameter differences affect filament strength by as much as ten Newtons.

In summary, diameter control during secondary and direct dry drawing is critical for control of filament strength control due to differences in surface area for smaller diameter product and small surface area to volume ratios for larger diameter product.

Final patenting

The DV calculation (Diameter times Velocity) is used to determine line speed when processing wires of different diameter simultaneously through one patenting furnace. However, this calculation should be limited to diameters that have surface area to volume ratio differences that are less than about 0.85 mm^{-1} as with a larger ratio it becomes difficult to properly heat both diameters simultaneously for differences outlined above. Table 2 shows that based on the surface area to volume ratio the DV calculation can be used to determine the line speeds of 1.20 and 1.60 mm product and 1.60 and 2.00 mm product processed simultaneously. However, the surface area to volume ratio difference for 1.20 mm and 2.00 mm product is too large to set line speed based upon DV when processing these diameters simultaneously. In this case the actual wire temperature during patenting should be used to help determine proper speeds. Mismatched DVs for large differences in surface area to volume ratio can affect filament

Speed (m/min)	Diameter (mm)	DV (m-mm/min)	Equivalence Speed (m/min)		Surface Area (mm2)	Volume (mm3)	Surface Area/Volume (mm-1)
55	1.19	65.5	55.0		3.74	1.11	3.36
55	1.21	66.6	54.1		3.80	1.15	3.31
Difference	0.02	1.1	0.9	Average	3.77	1.13	3.33
41	1.59	65.2	41.2		5.00	1.99	2.52
41	1.61	66.0	40.7		5.06	2.04	2.48
Difference	0.02	0.8	0.5	Average	5.03	2.01	2.50
33	1.99	65.7	32.9		6.25	3.11	2.01
33	2.01	66.3	32.6		6.31	3.17	1.99
Difference	0.02	0.7	0.3	Average	6.28	3.14	2.00

Table 2. Diameter, speed, and volume.

strength of 0.40 mm filament by as much as 15 Newtons.

Scale Formation. Scale formation results in wire surface material loss. Excessive wire diameter loss results in low filament strengths due to reduced true strain and uneven wire temperature across the patenting furnace. In general, material loss reduces filament strength and high wire temperature associated with uneven wire heating raises filament strength.

Furnace precoats can be applied to help reduce and control wire scaling during patenting. Precoats can alter reactions at the wire surface at austenization temperatures by creating a local atmosphere around individual wires. Some precoats can aggressively attack furnace insulating materials resulting in premature failure of these furnace components. Countermeasures can be employed to help extend furnace life.

As noted earlier, three reactions (iron oxidation, a reaction between carbon, water vapor and other gases and reduction of scale to form pure iron) can occur in the patenting furnace at the wire surface, particularly when wire temperatures are excessive. The first and last reactions are key to controlling scale formation. In general a properly set-up final patenting furnace and subsequent pickling operation will reduce a wire's diameter a surprisingly consistent ten microns. However, under improper combination of wire temperature, furnace atmosphere and precoating agent, scale volumes can more than quadruple, resulting in excessive scaling and wire diameter loss. Under extreme conditions scale formation can completely clog the furnace outlet in just a few hours.

Neck-down. Necking-down or reduction of diameter due to high wire tension at austenization temperature in the patenting furnace results in reduction in filament strength due to reduced true strain.

Heat transfer rate, wire temperature and decarburization. Wire temperature during austenization is generally proportional to austenitic grain size, degree of carbide dissolution and pearlite colony size. All of these mechanisms affect filament strength. It is not uncommon for filament strength variation due to differences in wire temperature to be in the range of seven Newtons for 0.20 high tensile filament.

Earlier comments on intermediate patenting about the effects of partial and full decarburization on filament strength also apply directly to final patenting. A high tensile wire partially decarburized during final patenting and successfully drawn to 0.20 mm can result in filament strength that is five to seven Newtons lower than expected.

One of several keys to decarburization control is regulation of heat transfer rate from the furnace and furnace atmosphere to the wire. Two prominent forms for heat transfer during austenization are convection and radiation. Regardless of the controlling heat transfer rate, the driving force for heat transfer is temperature difference between wire and furnace. However, presence of a driving force does not indicate the magnitude of heat transfer. For example, under identical furnace-loading conditions, identical final wire temperatures can result from furnace temperatures of 1070°C and 1030°C.

Mechanisms controlling convection and radiation differ significantly. It is relatively easy to control furnace temperature but it is more difficult to control furnace atmosphere composition.

Fig. 1 shows wire temperature as wires move through a 30 meter long furnace. Wires enter the furnace on the left at room temperature and exit the furnace on the right at 985°C. Wires are identical in diameter, chemistry and furnace speeds. The variable is furnace atmosphere composition, which results in a change of heat transfer rate.

Although the driving force for heat transfer is identical, namely a furnace temperature of 1070°C, wires heat at a different rate due to furnace atmosphere differences. Identical wire temperatures as wires enter and exit the furnace do not necessitate identical mechanical properties or filament strengths; mechanical properties for atmosphere 1 will be significantly different than those of atmosphere 2. Filament strengths for the three conditions illustrated in Fig. 1 can differ by as much as seven to ten Newtons at 0.20 mm for a high tensile product.

Effect of microstructure. Tensile strength and work hardening rate of coarse pearlite are lower than fine pearlite resulting in lower filament strength after wet drawing. Tensile strength of bainitic structures is higher than fine pearlite while work hardening rate is lower generally resulting in lower filament strength after wet drawing. Fig. 2 shows the relationship between microstructure and filament strength.

Alloying. Patenting issues are exacerbated when alloying is employed. Alloying results in the TTT curve shifting up and to the left and the transformation to fine pearlite begins at higher temperatures and shorter times. Alloying may limit patenting line speeds especially in the presence of strong carbide strengtheners or formers. Existence of complex carbides may require significantly longer austenization times or more realistically, higher patenting temperatures. For large diameter alloyed product safe furnace operating conditions can be exceeded.

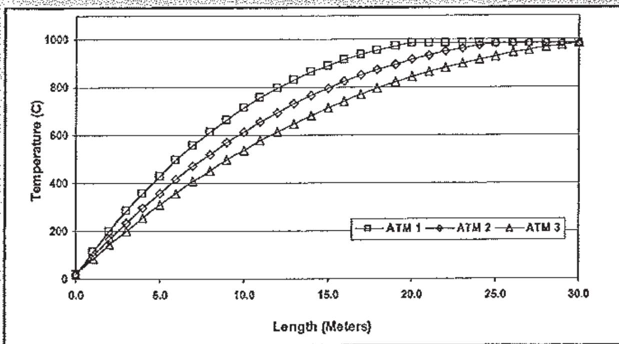

Fig. 1. Final patenting austenization wire temperature.

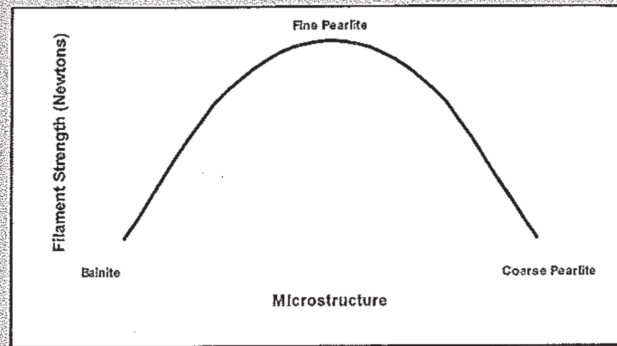

Fig. 2. Microstructure influence of filament strength.

Soaking conditions. Patenting soaking conditions influence filament strength by changing the cooling rate and temperature profile, particularly for large diameter and alloyed steel. For sand fluidized bed patenting the quench temperature and length should be optimized based upon the wire diameter, alloy content and patenting speed as illustrated in the following models.

Figs. 3-7 illustrate cooling curves generated from a proprietary heat transfer model with variables of wire diameter and speed and quench and soak temperature. Classical transformation curves are shown on the diagrams to illustrate where transformation begins and ends as well as the type of microstructure expected. All figures were generated for 2.1 mm eutectoid steels for simplicity. The figures will demonstrate effects of wire speed and cooling rate on expected microstructure. Note that in all figures the horizontal axis is time in seconds not length in meters.

No Quench. Fig. 3 illustrates effects of cooling after austenization utilizing a sand fluidized bed held at a constant temperature of 555°C. Quenching conditions result in large amounts of coarse pearlite which reduces filament strength. The model suggests that two step cooling (quenching followed by soaking) should be employed to initially increase heat transfer rate. As expected, quench rate and resulting microstructure are independent of wire speed. Filament strength at 0.40 mm for material produced under conditions demonstrated in Fig. 3 will be as much as 15 Newtons lower than expected.

Quenching & Soaking. Fig. 4 shows that a one meter quenching zone maintained at 480°C results in slightly less coarse pearlite than the previous model regardless of processing speed. Processing at slower speeds improves microstructure by obtaining the soaking temperature more rapidly. However the model indicates that the quenching heat transfer rate is too low to quench large diameter product to the left of the TTT begin curve. Filament strength at 0.40 mm for material produced under conditions demonstrated in Fig. 4 will be as much as 10 Newtons less than expected.

Increased quench length. Fig. 5 shows that a two meter quenching zone maintained at 480°C does not eliminate the coarse pearlitic microstructure. Patenting at 40 m/min shows quench under cooling. The minimum wire temperature is 492°C using this model. Increasing speed to 60 m/min improves under cooling; the minimum wire temperature is 537°C. In practice it is unlikely that patenting line speed can be increased 50 percent without serious consequences in other areas. The model again indicates that the heat transfer rate is too low to quench the large diameter product to the left of the TTT begin curve. Both speed conditions produce bainite and degenerative pearlite, lowering filament strength. Higher speeds reduce effects of microstructure. Filament strength at 0.40 mm for material produced under conditions demonstrated in Fig. 5 will be as much as 20 Newtons lower than expected.

Lower quenching temperatures. Fig. 6 shows that reducing quench temperature to 250°C using a one meter quenching length yields optimum results at 40 m/min. At 40 m/min some under cooling (537°C) exists, but duration is less than 0.30 seconds. The resulting

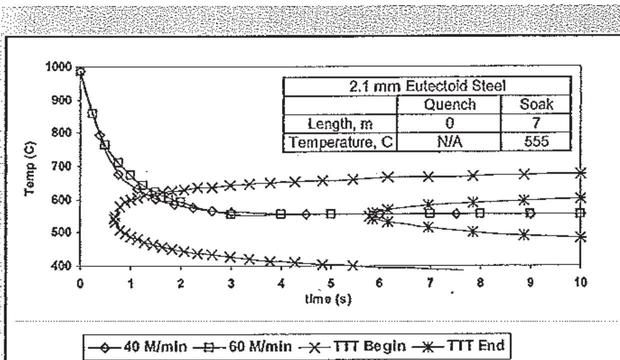

Fig. 3. Fluidized bed patenting.

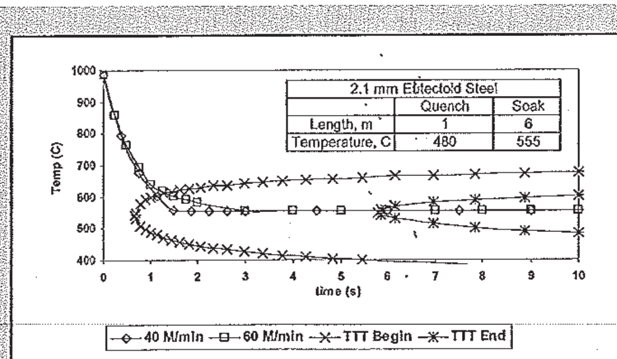

Fig. 4. Fluidized bed patenting.

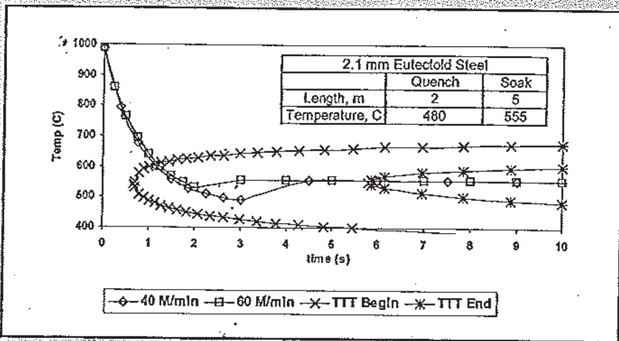

Fig. 5. Fluidized bed patenting.

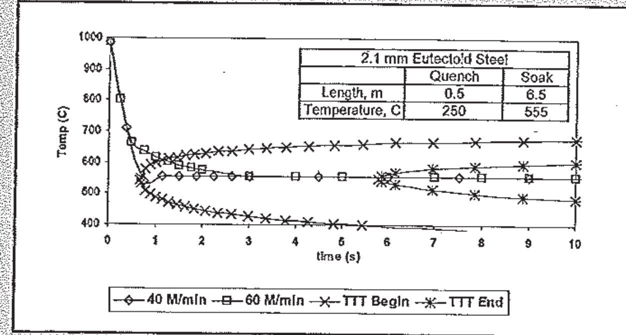

Fig. 6. Fluidized bed patenting.

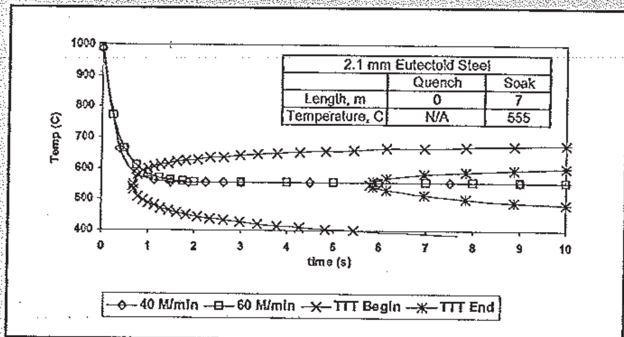

Fig. 7. Lead patenting.

Drawing Speed (m/s)	Filament Diameter (mm)	Filament Strength (N)	Cable Strength (N)	Cabling Efficiency
10	0.20	105.8	1201	94.6%
15	0.20	107.3	1201	93.3%
23	0.20	110.9	1201	90.2%

Table 3. Filament strain aging.

microstructure will contain very small amounts of degenerative pearlite and the highest filament strength among the four models. Filament strength at 0.40 mm for material produced under conditions demonstrated in Fig. 6 for 40 m/min will be nearly as expected.

Lead patenting. Fig. 7 demonstrates that lead bath patenting can be controlled by changing molten lead temperature and wire speed. Quenching rates are faster than sand fluidized bed patenting due to the higher heat transfer rates for liquid lead versus fluidized sand. The model shows that lower speeds reduce the amount of coarse pearlite. With proper lead temperature and wire speed near perfect microstructures can be developed. Filament strength at 0.40 mm for material produced under conditions demonstrated in Fig. 7 for 40 m/min will be nearly as expected.

Plating

Plating effects on filament strength are minimal except for presence of excessive beta brass which can increase strain aging during fine drawing.

Diffusion processes

When sequential plating and diffusion processes are employed, regardless of the method of diffusion, excessive diffusion temperatures reduce filament strength by as much as ten Newtons at 0.20 mm diameter in extreme cases. Two mechanisms play a role in this phenomenon: reduction in plated tensile strength and reduction in work hardening rate.

Wet drawing

Strain aged filament. Changes in fine drawing drafting can affect apparent filament strength by changing the amount of process-related strain aging. Similar effects are apparent for changes in wet drawing speed and lubricity. Wet drawing strain aging artificially raises filament strength while twisting relieves influences lowering apparent cabling efficiency. Strain aging can also occur when filament is stored either at relatively high temperature for short periods of time of for long periods at relatively low temperature. When using filament strength as a control point, procedures should be in place to help ensure that filament is tested in the non-strain aged condition. Effects of filament strain aging on apparent filament strength and cabling efficiency are shown in Table 3.

Filament diameter. Filament diameter can change apparent filament breaking load through changes in mass of material present. Since filament and cable strength are measured in units of force rather than pressure an average diameter is assumed for all filament. Changes in filament diameter can alter the apparent breaking load in accordance with Table 4. There are several methods of correcting for diameter when determining a corrected breaking load. A simple one is to assume that every micron of material in a diameter range near the average supports an identical load. This value is listed as Breaking Load per Diameter (mm) in Table 4. Using this concept all filament breaking loads listed in Table 4 are identical (110 Newtons).

Filament diameter ranges are set by customer's specifications, generally specific diameter requirements and cable linear density specifications. Diameter requirements limit minimum

Diameter (mm)	Breaking Load (N)	Tensile Strength (Mpa)	Breaking Load per Diameter (N/mm)	Corrected Breaking Load at 0.20 mm (N)
0.196	107.8	3573	550	110
0.198	108.9	3537	550	110
0.200	110.0	3501	550	110
0.202	111.1	3467	550	110
0.204	112.2	3433	550	110

Table 4. Diameter effect on breaking load.

Filament Diameter (mm)	Filament Strength (N)	Cable Strength (N)	Cabling Efficiency	Cable Strength Strain Aged at 150 C (N)
0.350	310	1488	96.0%	1563
0.350	288	1372	95.3%	1543
0.350	312	1509	96.7%	1576

Table 5. Cable strain aging.

and maximum single filament diameters in a cable. Cable linear density requirements help ensure all filaments are not at filament specification extremes. Some tire manufacturers include Ppk requirements for linear density or filament diameter or both. Ppk requirements help ensure actual data tend toward specification midpoints.

Another consideration is that cable is manufactured by length and sold by weight. This encourages cord manufacturers to produce toward the upper end of the filament diameter and linear density specifications. Ppk requirements can generally be met under these conditions by reducing standard deviations; the standard deviation appears in the Ppk calculation denominator.

Cabling

Cabling effectively lowers breaking load beyond the sum of the breaking loads of all filaments in a cable. This is generally reflected in the cabling efficiency, actual cable breaking load divided by the sum of the filament breaking loads prior to twisting. As stated earlier, this number is generally unchanged for a given cable and twisting machine setup but it can be influenced by filament strain aging. Filament strain aging is relieved in twisting reducing the apparent cabling efficiency. The mechanism causing a breaking load reduction in non-strain aged twisted filament is the effect of pulling filament off the central axis inducing shear loading.

Strain aging. Many tire cord specifications do not prohibit strain aging after twisting and before final release testing. Unlike strain aged filament there are little to no deleterious effects of strain aging on cable. In fact the curing temperature for rubber during tire manufacture is coincidently nearly identical to optimum temperature for strain aging plain carbon steel; all steel tire cord is strain aged during the tire curing process. Most cable constructions can be strain aged after twisting to increase the apparent cable breaking load. Table 5 shows typical breaking load results of some cable both before and after strain aging. Cable strain aging can be induced when cable temperature during twisting or cable storage temperatures after twisting are excessive or moderate and of long duration.

Summary

The many influences of raw material and manufacturing on steel tire cord filament strength have been reviewed. Steel tire cord manufacturers should be cognizant of strengthening mechanisms and their impact on the tire cord manufacturing process. Technical manufacturing systems should be instituted to evaluate effects of each mechanism on the steel tire cord manufacturing process on a continual basis using standard statistical techniques. Control of strengthening mechanisms that dramatically impact manufacturing efficiencies is key to survival in a competitive market place.

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Exhibit 2

THIS EXHIBIT IS NOT SUSCEPTIBLE TO PUBLIC SUMMARIZATION