IRLE´S HSS GRADE FOR F5-7 WORK ROLLS*

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Abstract

High wear resistant HSS rolls are being successfully used in the first stands of HSM finishing trains since the early 1990´s. The strong demand of mill administrators to make them applicable also in the last stands of the finishing rolling mill is a major influence factor of R&D efforts at respective roll suppliers. Looking back to the successful replacement of ICDP and HiCr rolls by more economic HSS rolls in F1-4 in regard to the TCO, rolling mill managers wish to repeat such scale gain also at F5-7 stands. Actually used enhanced ICDP rolls wear faster, being the HSM stoppage factor. F1-4 HSS rolls can be used for example 3 times longer. There is an obstacle to be overcome by roll suppliers and end users to replace F5-7 rolls by HSS rolls. Stick and crack resistance properties of HSS need to be improved. As a worldwide known leading producer of cast rolls for steel mills since 1820, the traditional German family owned foundry and machine shop IRLE, existing since 1693, accepted to face also this additional challenge. IRLE´s long year experience and prior researches have shown possible development directions to improve mentioned stick and crack resistance properties of its HSS grade, called SST. A new material of the HSS family is in the development pipe line and is discussed: SST/G. Choice criteria of the development direction, steps to control and guarantee respective sections of an industrial scale production as well as observations and results are described.

Keywords: Hot strip steel and plate mills; Work rolls; High speed steel; Material and production process improvements.

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1 INTRODUCTION

The IRLE Group is a traditional German family owned foundry and machine shop existing since 1693. IRLE is a worldwide known leading producer of cast rolls for steel mills, and non ferrous metal mills in general, since 1820. Since 1884 IRLE is producing also heated rolls for the paper industry as well as rolls for the plastic rubber and food industry later on [1,3]. Research and development (R&D) efforts performed at IRLE at a high and continuous level along the years since its foundation have enabled and ensured the company's leading position in the respective markets it serves.

This paper is focusing one of these recent efforts in products regarding the steel industry: the search of a suitable substitution, or at least a better alternative, to the so called enhanced indefinite chill, double poured iron materials (ICDP+). ICDP+ is a micro alloyed material with special carbide builders. This material is traditionally used at the shells of working rolls in the production of hot flat rolled steel. Such rolls have been assembled in the last finishing stands (e. g. F 5-7) of hot strip mills (HSM) since the end of the 1990´s. They are mainly being produced by spin cast machines (centrifuges) since then. IRLE produced - according to its own patent - the world's first centrifugal cast rolls and has actually the biggest vertical spin cast machine installed in the world [1,3]. The main disadvantage of ICDP+ is its performance wear ratio as well as the loss of hardness with decreasing outer barrel diameters in comparison to materials such as high speed steel grades (HSS). Therefore, a suitable substitution of ICDP+ could be a less radial hardness losing material towards the center line, similar to what HSS is. High wear resistant HSS rolls are being successfully used in the first stands of several hot strip mill finishing trains (typically stands F1-4) since the early 1990´s. A tough competitive environment in a steel industry shaped by oversupply leads the search for efficiency increase and cost reduction in the mills. The strong demand of mill administrators using such HSS rolls to make them applicable also in the last stands of the finishing rolling mill (typically stands F5-7) is a major influence factor of R&D efforts at respective roll suppliers. Looking back to the successful replacement of double poured indefinite chill (ICDP) and high chromium (HiCr) rolls by more economic HSS rolls in F1-4 in regard to the total cost of ownership (TCO), rolling mill managers wish to repeat such scale gain also at F5-7 stands. The actually used enhanced or micro alloyed ICDP rolls (ICDP+) in this mill stands wear faster, being the HSM bottle neck and stoppage factor, while F1-4 HSS rolls can be used, for example, 3 times longer.

2 MATERIAL AND METHODS

2.1 Mill Stoppage Costs x Development Efforts on F5-7 WRs

As a HSM works as a continuum in the production of steel coils, the first roll that needs to be changed or regrind due to wear, stops the entire production line of steel coils (compare with figure 1). Such a production line stoppage has a considerable cost factor related to capital expenditures (CapEx) - expensive machines and equipments, and to operation expenditures (OpEx) - men, utilities power, maintenance, installation availability costs. In a chosen generic example of a mill in Europe such cost amounts 2.000 €/minute of line stoppage. Unplanned stoppages can even have much higher costs. The loss of earnings is a further alternative, the other way round and a function of the maximal line productivity and achieved market

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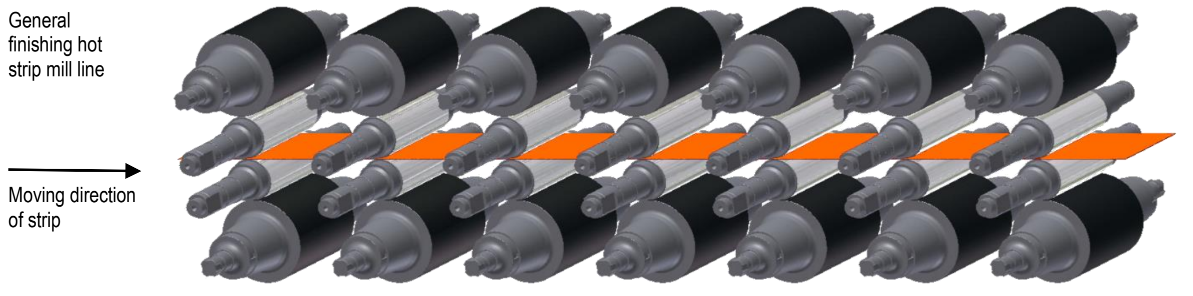
profits for a given product, to calculate or estimate the cost factor of a rolling mill stoppage. Even if a roll change can be done in few minutes nowadays in modern and highly automatic rolling mills, due to the high stoppage costs of the equipment, only a small performance increase in such a bottle neck roll, postponing whole mill stoppage and increasing campaign length, is easily sufficient to cover cost and efforts invested in such a performance increase of this roll. In modern and deeply automated lines a work roll (WR) change is done in less than 10 minutes (=> 10 x 2.000 = 20.000 € stoppage costs / change). Change of rolls with shortest production cycle life time due to wear (usually F7 in ICDP+ quality) will happen, for example, roughly each 5 hours, which in this case means, roughly about each 100 Km of rolled steel. Numbers are mean values of a chosen generic mill in Europe and for a given product (=> ~ 4,8 x 20.000 = 96.000 €/24h of stoppage costs). In other words, a performance increase in the bottle neck roll normally leads to a very short return of investments (ROI). No wonder that major players in the market (roll makers, mill suppliers, hot rolled steel coil producers) are all striving towards higher wear resistant materials for these applications and for an efficiency increase.



Stand name	F1	F2	F3	F4	F5	F6	F7
WR shell material	HSS	HSS	HSS	HSS	ICDP+	ICDP+	ICDP+
Rolled strip before stop to regrind WR due to wear [Km]	300	300	300	300	100	100	100
WR change frequency based on the roll with longer cycle life time	1	1	1	1	3	3	3
Example of rolling force F [kN]	19.500	19.000	15.000	13.600	12.600	11.500	11.000
Contact segment b [mm] - see figure 2	69,81	66,94	50,21	44,20	34,19	28,33	21,51
Pressure P on WR contact surface [kPa] - see figure 2	174.581	177.398	186.716	192.308	230.331	253.706	319.619

Figure 1. Example of change frequencies and pressure on WR surface along HSM finishing line.

2.2 Challenges

New solutions never come without new problems and challenges. There is an obstacle to be overcome by roll suppliers and end users to replace F5-7 ICDP+ rolls by HSS rolls. If rolls with high wear resistant HSS shells are being successfully used in the first stands of several HSMs (F1-4), the advance of this material in direction to the last stands (F5-7) actually still increases some risks and the stability of the

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production line. If more or less predictable stoppages due to worn rolls are unwanted and their frequency should be kept as low as possible, unplanned stoppages due to broken rolls are completely unacceptable. Moving on the razors blade edge for roll makers often is a synonym to find the right balance between such antagonist characteristics of a roll as toughness and wear resistance. Roll toughness guarantees rolling mill production stability. Wear resistance in the end increases the availability of the production equipment. Production line stability risks introduced by the use of HSS shells at last stands of the finishing mill mainly comes from adhesion of rolled material to the working roll surface. Stick and crack resistance properties of the steel strip similar HSS roll material need to be improved to achieve needed properties. Eventually cooling and lubrication procedures of the rolls need to be revised. As a worldwide known leading producer of cast rolls for steel mills since 1820, the traditional German family owned foundry and machine shop IRLE accepted to face also this additional challenge. IRLE´s long year experience and prior researches have shown possible development directions to improve mentioned stick and crack resistance properties of its own HSS grade, called SST. As a consequence, a new material of IRLE´s HSS family was born, will further mature to be ready for high scale market introduction (2015), to finally leave the development pipe line within soon. The new material was baptized SST/G. Choice criteria of the development direction as well as observations and results are described in the following items.

But why there is higher rolled material adhesion to HSS roll surfaces while ICDP+ rolls run well without sticking effects? And why this problem with HSS is observed increasingly in the last stands (F5-7) than in the first stands (F1-4)?

Understanding this mechanism [4-7] is a major part of designing a respective new HSS quality suitable for a safe use at F5-7.

2.3 Comparison of ICDP+ with HSS - Some Hypotheses

There are some hypotheses to explain observed higher crack sensitiveness in field and adhesion properties of a steel strip to a HSS roll in comparison to an ICDP+ roll:

1) Starting on atomic scale: more similar crystalline structure of steel strip and HSS shell of roll than of steel strip and ICDP+ roll

2) Higher friction coefficient of HSS in comparison to ICDP+

3) Amount of graphite in the matrix structure. HSS materials in general as well as IRLE´s respective SST doesn't have any amount of graphite (0%). Compare figure 8. IRLE´s ICDP+ material (I *plus*) has an average content of 2% of graphite. Compare left side of figure 9.

4) Fracture toughness (K_{IC}) of ICDP+ ranges around 22 MPa√m while HSS values are a little bit higher, around 25 MPa√m. This is rather an indication that fracture toughness is not the driving factor or variable to be considered in regards to observed deeper crack propagation of HSS rolls in later stands of the finishing mill in comparison to ICDP+.

Further on, there are some hypotheses to explain why sticking characteristics of HSS are observed increasingly in the last stands (F5-7) than in the first stands (F1-4). Sticking characteristics may be the driving factor to an observed higher crack propagation degree of HSS in comparison to ICDP+ at WRs in later stands.

1) Decrease of temperature of strip from F1 to F7

2) Increase of contact pressure of roll to strip (deformation pressure of strip in kPa) - see figure 1, 2 and 3 and compare with equations 1 to 6 [8,9].

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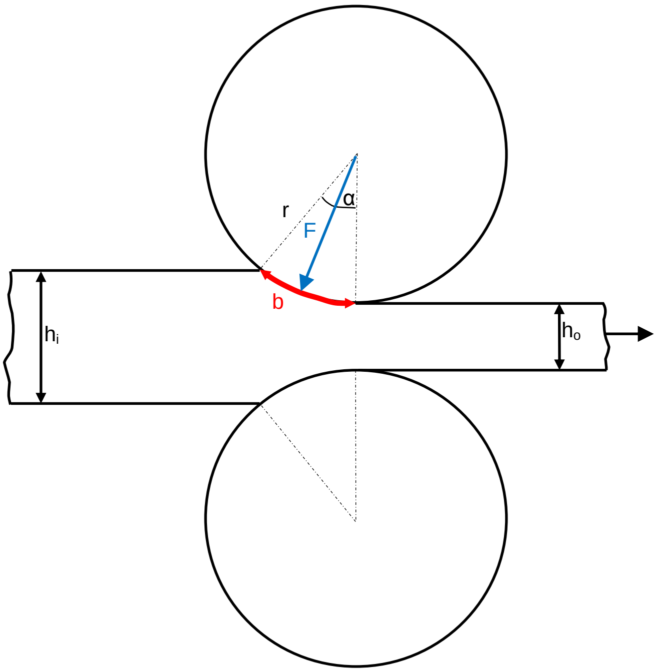
2.4 Some Theory Summarizing



$$b = \frac{\pi}{180} \times r \times \alpha \quad (1)$$

$$\alpha = f\,(h_i, h_o) \quad (2)$$

$$=> b = f\,(h_i, h_o, r) \quad (3)$$

$$P = \frac{F}{b \times w} \quad (4)$$

$$F = f(m, h_i, h_o) \quad (5)$$

$$=> P = f(m, h_i, h_o, r, w) \quad (6)$$

b = contact segment
r = roll radius
α = angle of contact segment
P = pressure on strip
F = rolling force
w = width of strip
h_i = thickness of strip in
h_o = thickness of strip out
m = properties of rolled material

Figure 2. Rolling geometry and simplified representation of resulting force F.

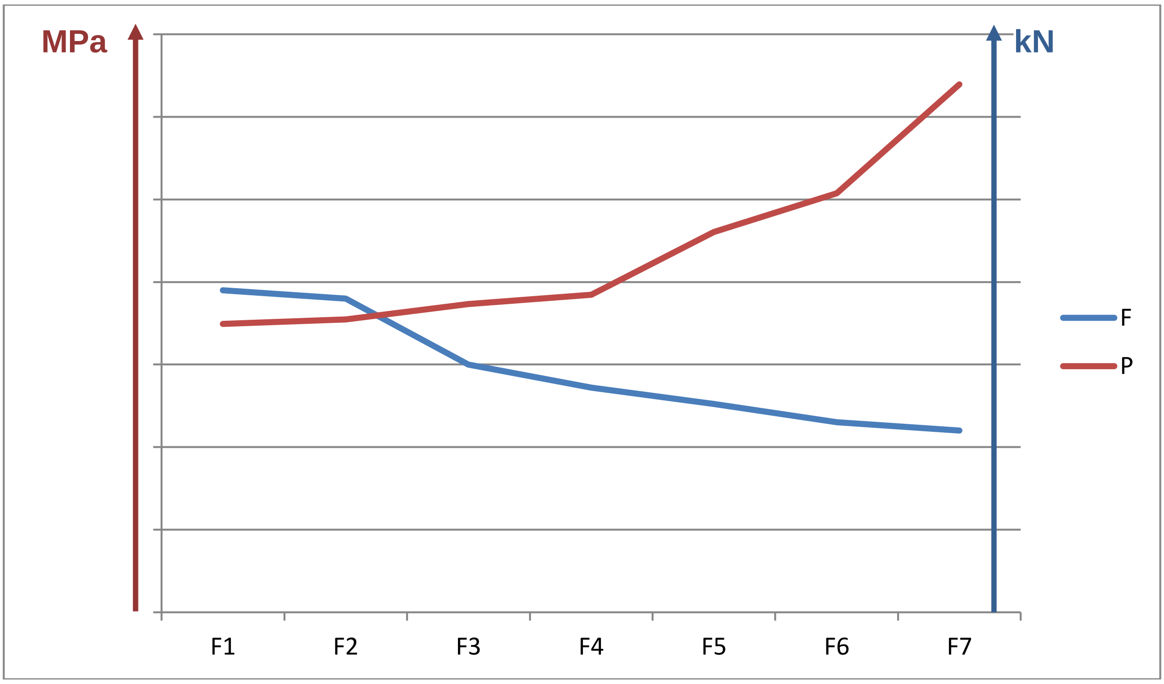


Figure 3. Increase of roll contact surface pressure P along rolling mill finishing stands while rolling force F itself decreases. Contact surface (b x w) decreases proportionally more than F, implicating in an increase of P.

In the search of conclusive answers and in the curse of more detailed investigation of above given hypotheses, IRLE´s R&D department decided to use a modern software based material design tool to find a first theoretical material composition. In a second step, the so designed material was evaluated with regard to material expert knowledge and cast ability. Furthermore, samples were cast and outcome analyzed and evaluated again in detail. Coming closer to an industrial scale production, a first

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spin cast roll was produced and deeply analyzed in regard to material structure and properties with some closer attention to hardness values. Compare also to figure 4.

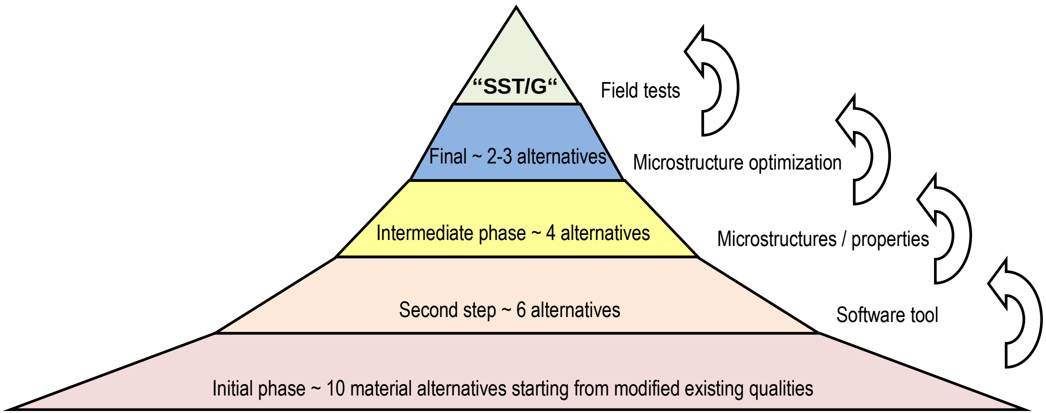

Figure 4. Development pyramid - steps and filtering tools to reach a target material.

2.5 Material Design with Software Tool

Input information to the software are mainly mass percentage composition of different chemical elements of a new created material design and eventually cooling temperature curves.

Accurate outputs are physics based and experience proven material characteristics like stable and metastable phase equilibrium, solidification behavior and properties, thermo-physical and physical properties, phase transformation and chemical properties.

With this tool, a wide range of properties such as strength, hardness, stress-strain curves, rupture strength, and so on, can be simulated with good accuracies for a series of material types before of cast even one single piece. This permits relatively low cost intense investigations for a searched new material just "playing" with or adjusting different inputs on chemical composition and temperature curves.

Naturally, the software operation demands scientists with deep material knowledge to evaluate the results and correctly correlate them to the searched material as well as to cast feasibility at given installations. At IRLE these are metallurgical scientists and cast engineers. The definition of the target in this case, that means, of the searched material, was given and directed by the answers IRLE´s R&D scientists found to the hypotheses studied in depth and summarized in 2.3 above. Compare figure 5.

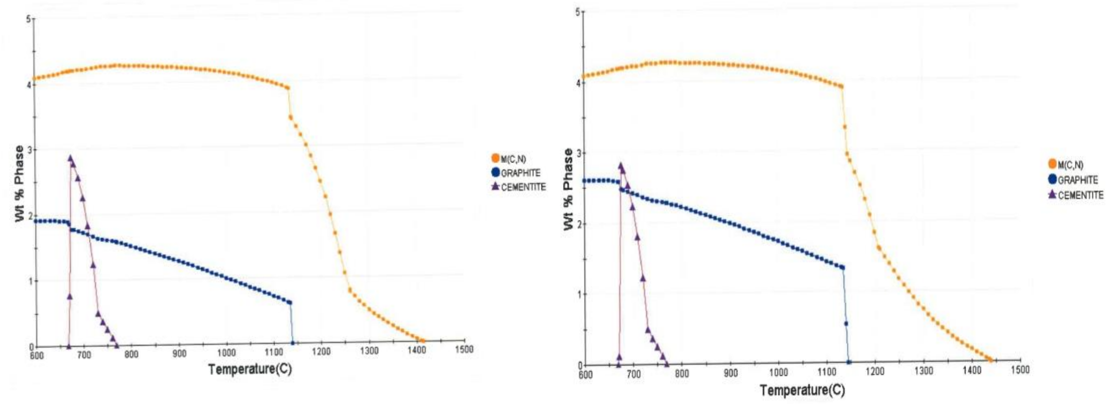

Figure 5. Software tool (JMatPro). Change in chemical composition contend (e. g. Fe) leading to an increased content of graphite without changing amount of carbides and cementite (compare left to right side).

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After founding the suitable recipe after several simulations, which accordingly to the described results could be a high wear resistant HSS material suitable for a F5-7 usage in a profitable exchange to the established ICDP+, the new material named “SST/G” was first cast at IRLE´s industrial facilities. The material properties achieved were then compared to the simulation results, proving a very accurate software tool with all outputs inside or below expected properties tolerances. See also figure 5. In a second logical sequence step, observed properties of the cast SST/G were compared to the existing HSS and ICDP+ materials, which are cast since long years by IRLE on its own horizontal/vertical spinning machines. IRLE´s HSS material is widely used and well known in the market as “SST”. Same passes to IRLE´s ICDP+ material, know in the worldwide market under the name of “I *plus*”.
Some of these comparisons between the HSS and ICDP+ with the newer born SST/G are summarized in the results in the following item.

3 RESULTS AND DISCUSSION

Metallographic pictures of the cast SST/G roll, taken at the barrel surface and 40 mm under barrel surface, are shown in figures 6.
For comparison, equivalent metallographic pictures of a SST and I *plus* are shown in figure 7 and 8.
At figure 9 the distribution and amount of graphite can be compared between the new SST/G and the traditionally used I *plus*.

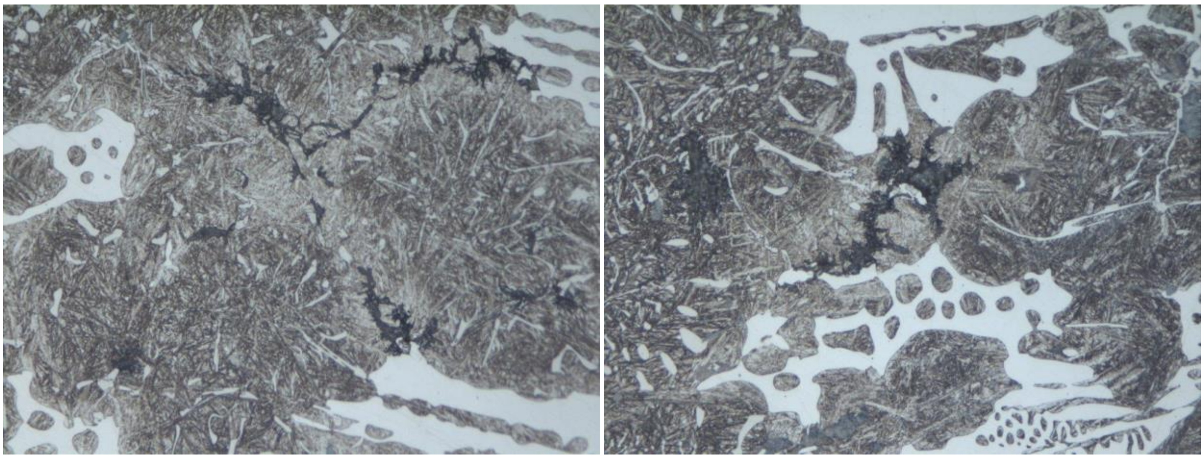

Figure 6. New material SST/G, roll barrel surface (left) and 40 mm under roll barrel surface (right), magnification 500 x.

In the bainite / martensite iron matrix there are still around 30% carbides. Especially a high level of fine dispersed alloyed carbides like VC, Mo_2C, W_2C and other composite carbides with high hardness values up to 3.000 HV are found. The right side shows the same high contend of carbides in the bainite / martensite matrix in 40 mm depth as on the surface area of the left figure – and also the same graphite formations are found at both compared levels. Therefore, hardness and abrasion rates are the same. This means a continuous high performance on a same level from the new diameter till the end diameter of the roll. This is very similar to HSS behavior.

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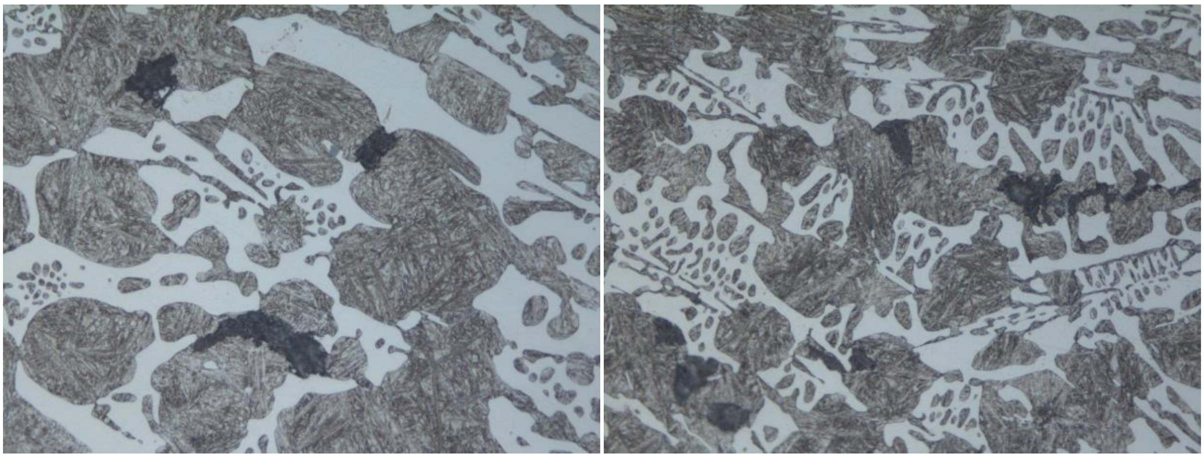

Figure 7. I *plus*, roll barrel surface (left) and 40 mm under roll barrel surface (right), magnification 500 x **-** standard indefinite texture with low content of special carbides.

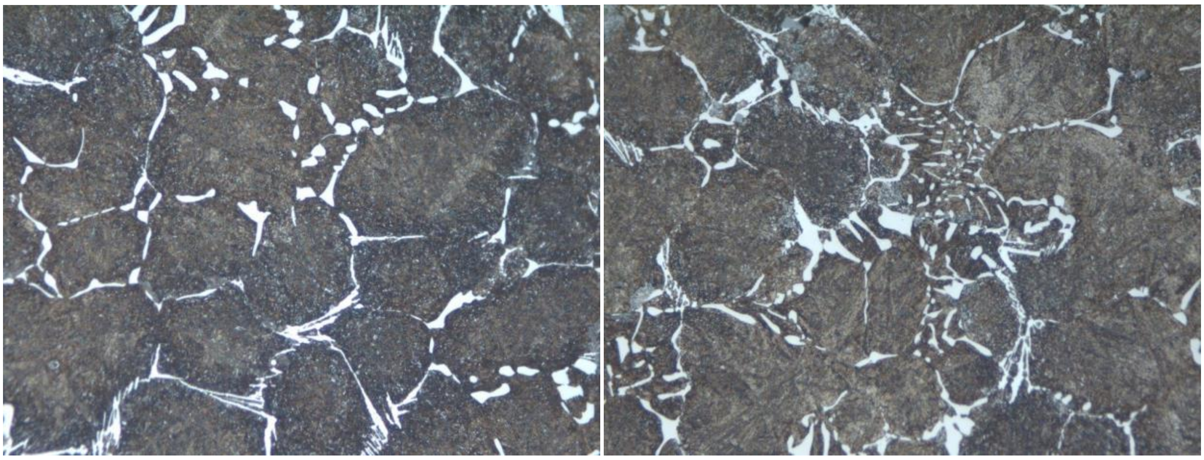

Figure 8. SST, roll barrel surface (left) and 40 mm under roll barrel surface (right), magnification 500 x - fine content of special composite carbides in martensite texture.

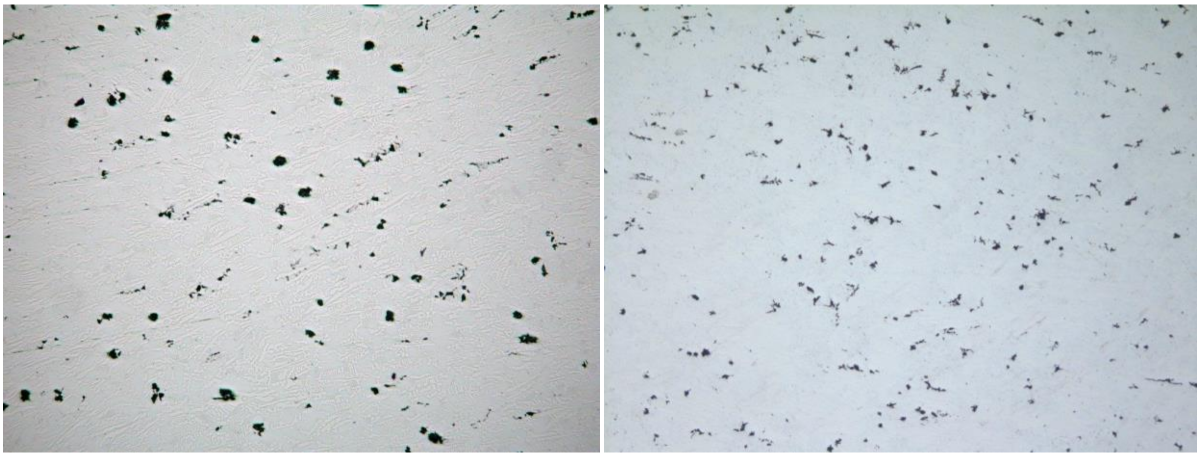

Figure 9. I *plus*, roll barrel surface, approx. 2% of graphite (left side) and new developed HSS material for F5-7 stands - SST/G, roll barrel surface, with approx 1,5-2% of graphite, magnification 100 x.

The hardness x depth curve (barrel surface in radial direction to center line of roll) of SST/G has been compared with HSS and I *plus* - see figure 10.

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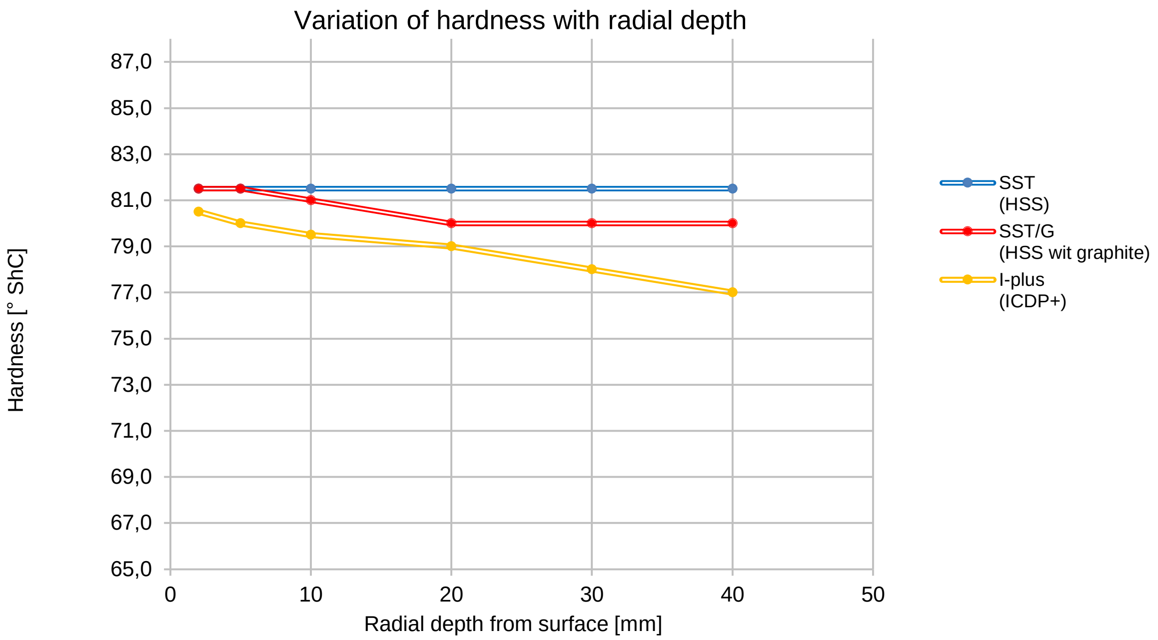

Figure 10. Hardness penetration curve of SST/G in comparison to SST and I *plus.*

4 CONCLUSION

Comparing figures 6 with figures 7 and 8, as well as observing the comparisons shown in figure 10 brings us to the conclusion that the new SST/G material has some main properties that lay between respective properties of HSS and ICDP+, coming close to HSS specially in regards to uniform hardness (based on special carbide content) in radial depth direction (figure 10). This is a very important advantage of SST/G to ICDP+ materials in regards to the expected wear resistance properties.

In the comparison of the graphite amount of figure 9, one of the properties suspected to be responsible for better or worse stick resistance characteristics accordingly to hypothesis shown in 2.3, the new SST/G material has almost reached similar precipitation of graphite as ICDP+ (~2%). The development target to create a comparable graphite formation and distribution (ICDP+ / SST/G) was reached.

Further investigations shall be done to deepen knowledge and for a better understanding of driving mechanisms of crack propagation of apparently ambiguous behavior of HSS and ICDP+ rolls when used at last stands in regards to their fracture toughness values.

SST/G will soon be the market mature material to gradually substitute ICDP+ materials in the last stands (F5-7). Larger field test are already planned at key customers and further results are being collected and compiled to be published in a following paper.

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