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HIGH PERFORMANCE WORK ROLLS FOR ROD AND BAR MILLS[1]

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Abstract
High performance rolls and rings help to increase mill performance and efficiency. In the finishing stands, many mills already use high tech materials, such as carbide rings. Whereas in the roughing and intermediate stands, standard monocast nodular iron rolls, with moderate performance are still used. Spin casting technology offers a huge potential for improvement of roll life in the roughing and intermediate stands, increasing mill efficiency. New roll materials, containing high hardness carbides, have been developed and are now utilized in various applications, including slitting.
Key Words: Rolls; Carbide; Slitting.

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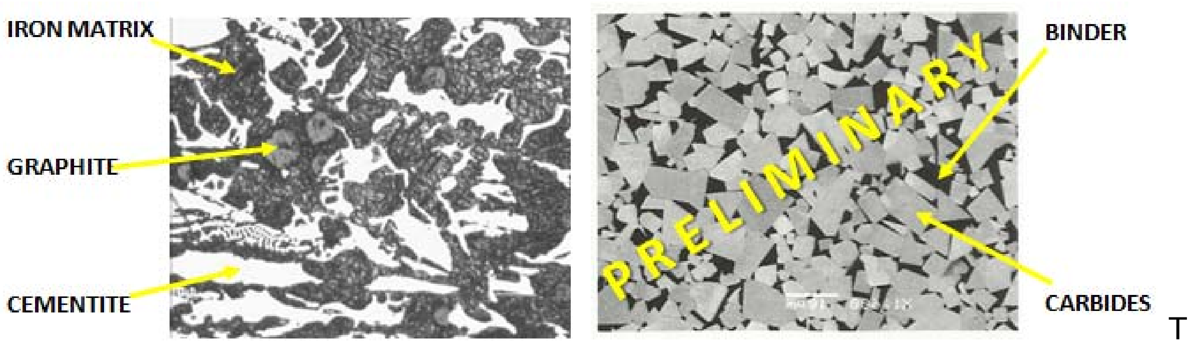
1 INTRODUCTION

When rolling, rod and bar, maintaining tight tolerances and good surface finish, has always been a challenge. Cemented carbide rings have a proven history in this application, and can be regarded as a 'state of the art' solution.
In the pre–finishing and intermediate stands, the situation is quite different. In most cases, you will find static cast, spheroidal graphite bearing rolls or rings, with either a pearlitic (SGP) or acicular (SGA) matrix. The most common hardness range is 60 – 65 Shore C for the intermediate stands and 70 - 75 Shore C for the pre – finishing stands.
A review of the microstructures of the SGP and SGA rolls, compared to carbide rings, will immediately highlight the shortcomings of these established roll grades.
Figure 1 shows the microstructure of a carbide ring (right picture), using high magnification (1600x). You will find small sized high hardness carbides in a homogeneous Cobalt or multi Co-Ni-Cr based binder.
Looking at a typical acicular iron structure (left picture) at a much lower magnification, you will note some significant difference:

- the microstructure of SGA is much (!) coarser;
- SGA contains free graphite particles, and coarse eutectic carbide (cementite), which are not present in the carbide ring structure
- the acicular matrix is much coarser than the structure of the binder in the carbide rings.



SGA 75 ShC M=100x C 85 ShC M=1600x

Figure 1: Left: microstructure of a conventional static cast acicular nodular iron roll; Right: typical cemented carbide ring microstructure.

This comparison gives an explanation for the huge difference in wear resistance and performance between the finishing rings and the iron pre – finisher rolls. The coarse graphite in the SGA roll is very soft, and an ideal starting point for immediate wear in service. The coarse and brittle cementite particles may easily fracture under load, and the low alloy matrix cannot keep them in place, so they are torn out of the roll surface, thus increasing roughness and wear.
As a consequence of this low wear resistance, the shape of the product leaving the pre- finishing stands cannot be controlled over an extended service period. This may damage the performance level of the finishing rings, and even cause ring breakage.

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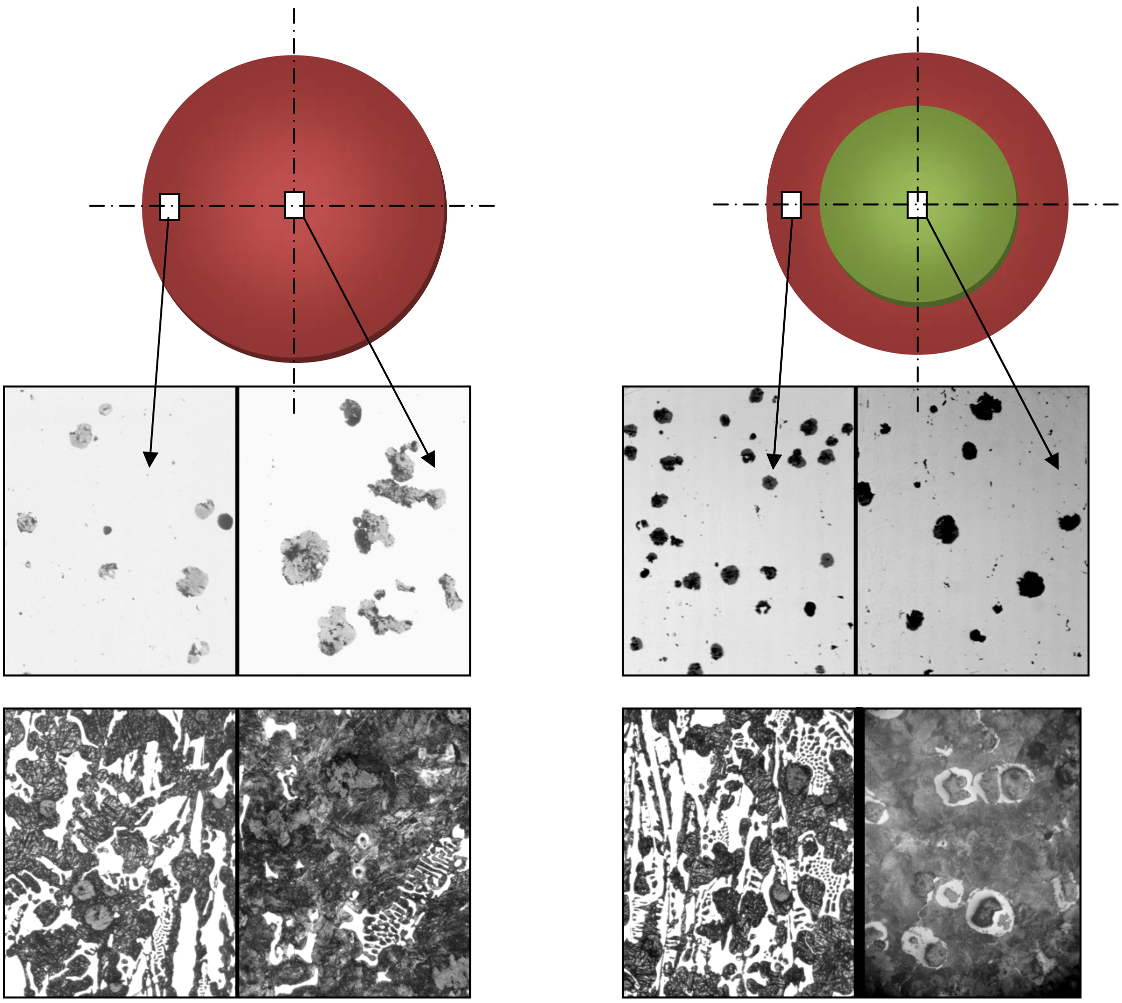
2 HOW TO IMPROVE THIS SITUATION?

Is there a cost effective metallurgical solution to provide rolls and rings for the intermediate and pre-finishing stands, that approximates to, or approaches the fine microstructure and wear resistance of the carbide rings?
We believe, there is a way to do things better.
The solution is: spun cast double poured rolls with optimized microstructure.
Let us examine this solution, and find answers to the following questions:

- Are double poured spun cast rolls suitable for this purpose, regarding usable diameter range, mechanical strength, and safety in operation?
- What needs to be done in the mill to use such spun cast rolls successfully?
- What kind of microstructures can be achieved in the working zone of such rolls, and how do they compare to carbide ring microstructures?

2.1 Suitability of Spun Cast Rolls for Intermediate and Pre-finishing Stands of Rod and Bar Mills

The main difference between static mono cast and spun cast double poured rolls can be seen and explained by looking at the cross section of such rolls (Fig. 2).



barrel – M=100x neck – M=100x barrel – M=100x neck – M=100x

Figure 2: Comparison of monocast and double poured spun cast rolls (cross section).

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Static cast rolls do not have a clear shell depth or defined working zone. They show finer and usually harder microstructure at the surface, and when you get closer towards the roll center, the microstructure becomes coarser and softer (and less wear resistant). This is determined by the solidification process during roll casting. The outer part of the rolls shows a “chill effect”, because after pouring the melt into the mould, the liquid metal comes into contact with the cold mould and solidifies rapidly, forming the outer part of the roll body. Within the roll, this chilling effect is greatly reduced, and the solidification rate slows down, resulting in a coarser microstructure, less carbide content etc. Such rolls show a significant hardness drop from the surface towards the interior of the roll. In the case of long product rolling, the hardness at the bottom of the roll pass is always lower than close to the roll surface, and the difference in hardness can be quite substantial, depending on roll type and roll quality.
Spun cast rolls are different. The melt which will form the working zone of the roll (“shell”) is being poured into a rotating mould and forms a tube of 30 – 80 mm thickness (in case of average sized rod and bar mill rolls). The solidification of this shell material is much faster than when static casting and the microstructure is very fine. Due to the high solidification rate, there is little difference in microstructure between the outer and inner part of the shell.
The solidified spun-cast tube is removed from the spinning machine and placed on a bottom neck mould, and a top neck mould is positioned. Core material is then poured into the assembly in order to form the roll core and necks. Careful control of the core casting temperature is essential to ensure enough shell material is being re-melted by the core material, in order to form a good bond between shell and core.
Considering the rolling process, it is clear that the maximum depth of the rolling pass is the radial thickness of the shell.
As long as the bottom of the roll pass is within this range, the microstructure and hardness at the bottom of the groove will not only be suitable for rolling, but will be better than that of a static cast roll, because of the faster solidification of the shell resulting in a superior microstructure.

2.1.1 Mechanical strength

Static cast rolls display some segregation between the surface and the centre of the roll core, but have a more or less uniform chemical composition throughout the whole roll body.
This means a wear resistant roll with high carbide content in the outer working zone of the roll will also contain a significant carbide content in the core and in the necks. This limits the breakage resistance of both roll body and the roll neck.
In the case of double poured spun cast rolls, the core and neck part of the roll will always consist of low alloyed, low carbide, nodular cast iron with a tensile strength of more than 400 MPa. This is almost independent from the chemical composition and type of shell material used. For this reason, the spin casting technology allows the use of very high alloyed roll materials like HSS.

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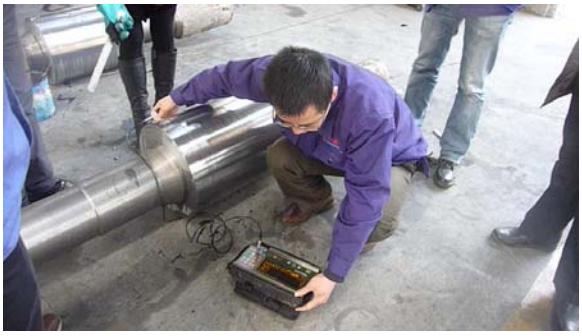
2.1.2 Safety in operation

The high core and neck strength makes the double poured roll the safer roll. The weakest point of such a compound roll is the transition zone between shell and core. This zone must be free from inclusions, porosities and other deleterious effects that might weaken the mechanical strength of the roll.

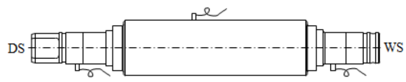
The integrity of the bond zone has to be proven by ultrasonic testing. Established testing methods have been in use for double poured flat product work rolls for many years, and these methods can be adapted for high tech long product work rolls. Fig. 3 shows the UT testing process of a double poured work roll, and the test certificate showing all relevant parameters of the roll and testing process.



UT Report

Workpiece	CC/SGA Roll	Roll No.	#	Foundry Code	180370CCA-19
Dimension	Φ370×930	Quality	SGA/DCI	Heat-treatment	As cast
Probe Type	B2S	Sensitivity	According to standard	Condition	after Rough-machined
Surface Roughness	Ra6.3	Model of Instrument	SS240	Velocity	5624m/s
Couplant	Machine oil	Location of Inspection	100% along the barrel、neck in radial direction; check the interface and shell thickness.		
Reference of the inpsection	UT Standard of AIC Roll				

test sketch：



No	Location of defects	Equivalent size of defect or echo height	Indicated Defect Length（mm）	Defect Depth（mm）	Rated Class

Conclusion:
Under 2MHz testing frequency:
Backwall echo of barrel in radial direction is sound;
Backwall echo of neck in radial direction is sound;
Interface condition: no defect larger than Φ5mm;
Shell thickness: 42～52mm.

Signature:	Mr. Shi	Qualification of Inspector	UT(Ⅱ)
Auditor		Report Date	2012-03-27

Figure 3: UT testing of a double poured spun cast work roll, 340x600 mm, and UT test certificate.

2.1.3 What needs to be done in the mill in order to use such rolls successfully?

High hardness, high wear resistant roll materials are less tolerant than soft, low-alloy roll types if exposed to mechanical and thermal overloads in the rolling process.

Good maintenance of the cooling system (adequate water pressure, unblocked nozzles) and good alignment of the mill stands and guides are basic needs for the use of high performance rolls.

Elevated water pressure and higher total amount of water available will play a major role when it comes to graphite free roll materials (HSS) and special applications (like slitting).

Good temperature control and throughput rate of the billet feedstock, avoiding cold bars in order to minimize the danger of mechanical shocks is essential.

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3 WHAT MICROSTRUCTURES CAN BE ACHIEVED IN SPUN CAST DOUBLE POURED ROLLS?

Figure 1 has shown the big difference between the graphitic microstructure of SGA, and the non – graphitic carbide ring. In principle, there are 2 different types of cast microstructures with improved wear resistance:

- Microstructures containing free graphite, and
- Non – graphitic microstructures.

3.1 Microstructures Containing Free Graphite

Improved microstructures that still contain a limited amount of graphite can offer improved wear resistance in mill stands that require graphitic roll types (for whatever reasons). Modern inoculation techniques and the use of special carbide forming elements help to create microstructures that are far superior to the microstructures of static cast SGA commonly in use.
In order to gain a significant increase in wear resistance, the microstructure has to fulfill the following requirements:

- Limited and well controlled amount of graphite
- Fine graphite particles
- Martensitic matrix
- Fine carbide dispersion
- High carbide hardness

3.1.1 Graphite

Both the amount and the shape of graphite particles needs to be controlled. Modern melting and inoculation techniques used in the production process offers a wide range graphite shape, size and distribution. Fig. 4 shows the microstructure of our basic monocast SGA 75 ShC compared to 2 types of improved spun cast graphitic microstructures, both in the hardness range 75 – 80 ShC. Type A shows compacted graphite, which comes close to nodular iron, whereas Type B shows elongated graphite similar to Indefinite Chill. It is interesting to note that both roll types have nearly identical chemical compositions, and the variation in graphite formation has been triggered by inoculation prior to casting. This shows the flexibility of modern roll making, allowing the production of application specific microstructures according to the mill´s requirements and operating conditions.

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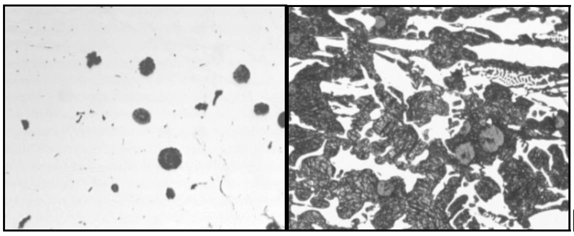

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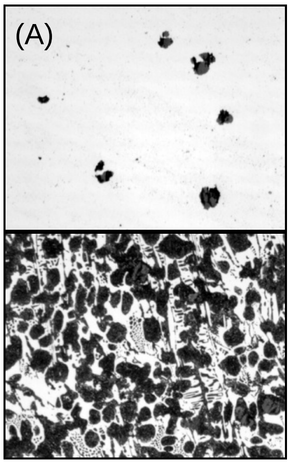
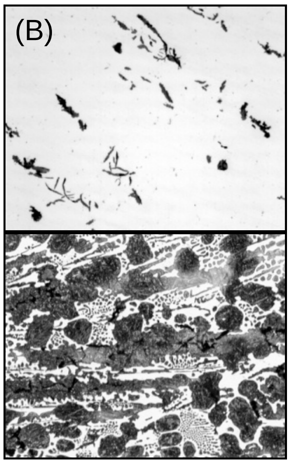
00x



M=100x

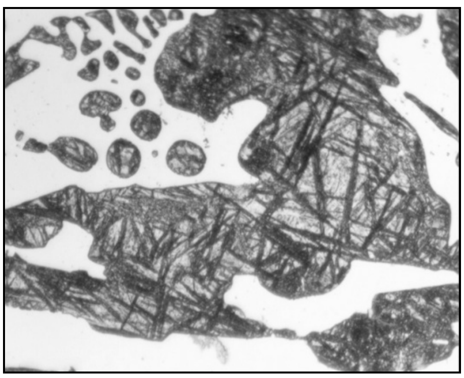


M=100x

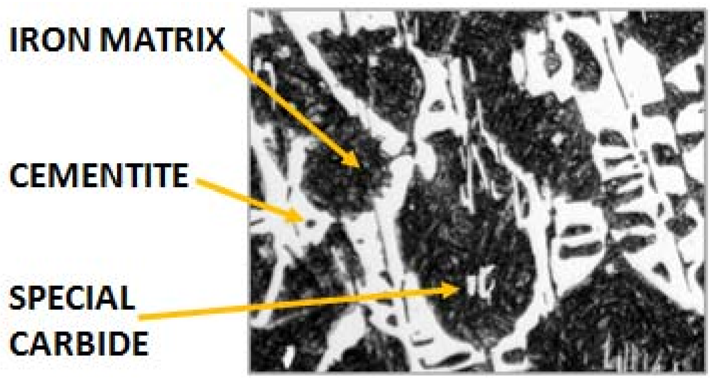
Figure 4: Comparison of microstructures, 100x magnification. Left: Basic static cast SGA 75 ShC. Right top (A): spun cast modified AIC with compacted graphite, 78 ShC; Right bottom (B): spun cast modified AIC with elongated graphite, 78 ShC.

3.1.2 Martensitic matrix

Roll production using the spin casting process offers the possibility to use higher alloyed shell material. The higher alloy content and the faster solidification during roll production lead to a refined martensitic matrix with higher microhardness, as shown in Fig. 5.



M=400x



M=400x

Figure 5: Martensitic structure, size and dispersion of carbides in the microstructure. Left: static cast basic SGA 75 ShC; Right: shell material of a double poured spun cast modified AIC, 78 ShC.

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3.1.3 Fine dispersion of carbides

The biggest improvement can be seen in carbide dispersion (fig. 5). It is possible to avoid huge agglomerations of eutectic carbide as seen in the SGA microstructure. Such chunks of carbide can easily break and are extracted from the roll surface, leading to high roughness and accelerated wear. A much finer dispersion of carbides will avoid this problem, and delay the initial stages of carbide breakage and wear substantially.

3.1.4 Carbide hardness

Standard SGA rolls contain cementite of a very limited hardness level. The spin casting process offers the possibility to use carbide forming elements that increase the carbide hardness dramatically. Fig. 6 shows carbide forming elements in use, and carbide hardness achieved.

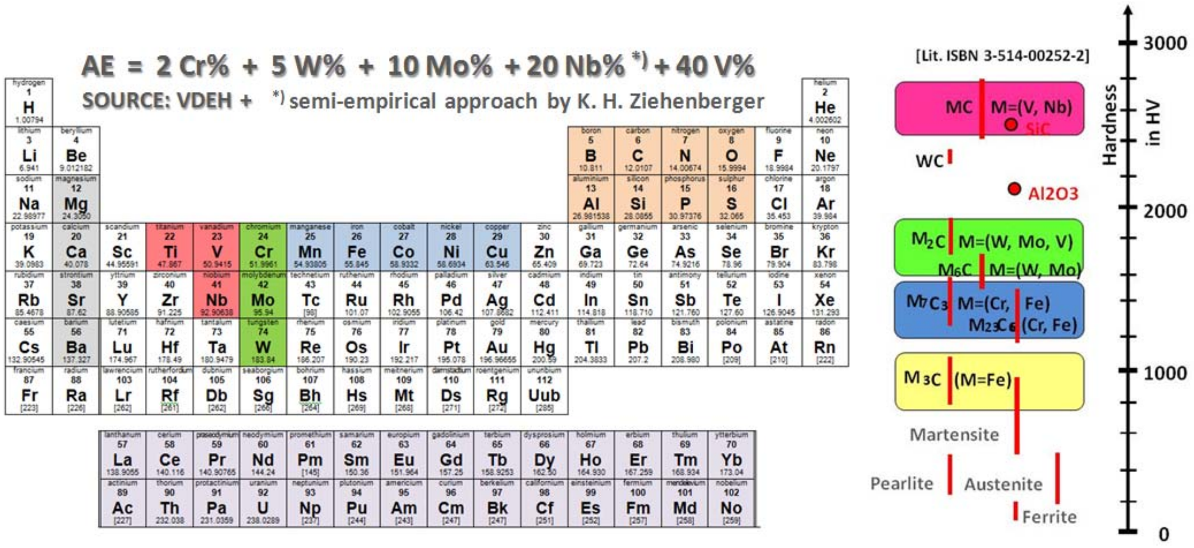

Figure 6: alloying elements used in roll making and hardness of iron matrix and carbides.

3.2 Non – Graphitic Microstructures

The absence of soft graphite particles in the working zone of a roll increases its wear resistance. The graphite free microstructure contains martensite and carbides (either eutectic or non-eutectic carbides). The development of such microstructures can be based on traditional chromium based rolls, or on HSS rolls. For highest wear resistance, the HSS type roll is the right choice.

3.2.1 HSS type work rolls for long product rolling

There is a wide variety of HSS roll compositions in use, mainly for flat rolling. For rolling long products, the HSS microstructure has to be adopted in order to fulfill the requirements of the working conditions that are typical for grooved rolls, e.g.: highly concentrated thermal load, high local mechanical forces, impact forces from cold bar heads and ends, etc.

Fig. 7 shows the comparison of a standard SGA microstructure (left side) and 2 different stages of HSS development: right on top, an early stage of development with fine microstructure but local concentrations of eutectic carbide. On the right side at the bottom, we can see a much refined HSS microstructure with no carbide

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segregations and uniform distribution of single carbides. It is interesting to note that the difference in chemical composition is rather small – the main factors influencing the microstructure are melting and casting parameters!

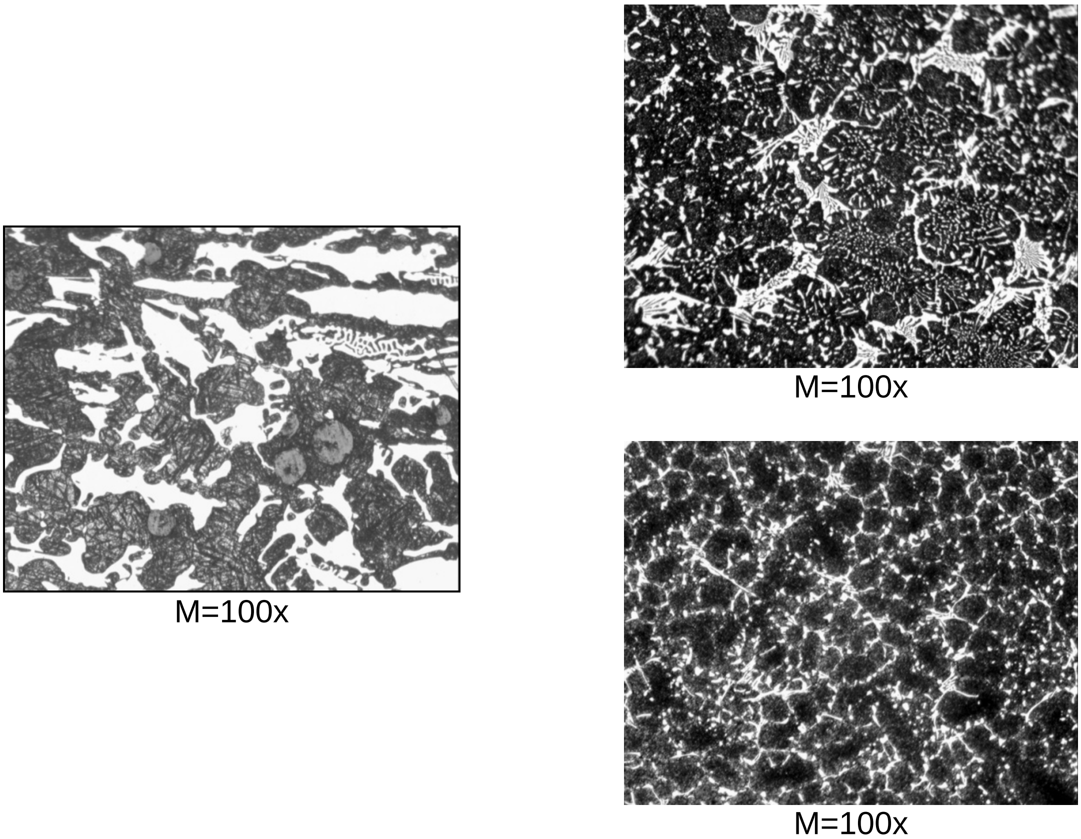

Figure 7: Comparison of microstructures, 100x. Left: static cast standard SGA 75 ShC. Right top: early stage of HSS development for long product rolls; Right bottom: refined and optimized HSS microstructure (improved machinability and performance).

4 ROLLING PRACTICE

Improved rolls with graphitic microstructure can replace standard SGA without modifications in the mill, like improved cooling. The hardness level of such rolls can vary between 70 and 85 ShC, and can be adjusted by variation of graphite content, content of high hardness carbides, and heat treatment.
Non – graphitic rolls like HSS will require good roll cooling and a well equipped and maintained machine shop. The rolls are suitable not only for simple rolling processes, but for the most demanding applications.

4.1 An example: Slitting

The slitting process is most demanding for the work rolls. It combines high local thermal load and high frictional forces at the same time. This leads to short campaign length, frequent roll changes, and in many cases to roll damage (chipping, collar breakage). The roll grades normally used (static cast SGA, conventional AIC) are not working effectively.

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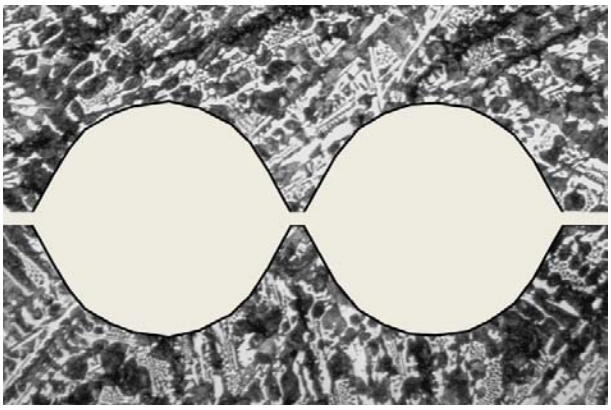
Fig. 8 shows how the microstructures of 2 different types of work rolls and of a cemented carbide ring would look like in the critical area of a slitting pass: On the top, conventional SGA 75 ShC with the typical coarse microstructure.

- On the bottom, the carbide ring with its high carbide content. It is difficult to achieve high wear resistance and good resistance to thermal overload in a roll material: A very high carbide content makes the ring wear resistant but heat sensitive. Using a lower carbide content (and, as a consequence, a higher amount of binder) will make the ring more forgiving, but may increase corrosion problems of the binder, resulting in high roughness and wear. So the rings are very sensitive concerning cooling and water quality (pH value).
- In the middle lies the spun cast HSS (latest stage of development with improved microstructure). The fine HSS microstructure will lead to less and much finer heat cracking when compared to the standard SGA, and the size of particles removed from the surface is at least 1 magnitude smaller than with SGA. This allows much longer campaigns, and less redressing after the campaign. Less cracking and finer microstructures reduce the risk of collar breakages, and increases the safety of the HSS rolls in use. When compared to the carbide ring, the HSS shows more matrix which can cope with the heat transfer required, and is less likely to suffer from minor deficiencies in the cooling system.

5 SUMMARY

In many rod and bar mills, state of the art carbide rings are in use for finish rolling. In the pre – finishing and intermediate stands, many mills still use static cast SGA rolls with typically coarse microstructures and limited wear resistance.
There are much better solutions available. Spun cast double poured roll types with improved microstructures have been developed to fill the gap between the costly and sensitive WC finishing rings and the low performance rolls conventionally used since 50 years.
In certain applications, modern spun cast roll materials may be a highly cost effective alternative to the use of cemented carbide.



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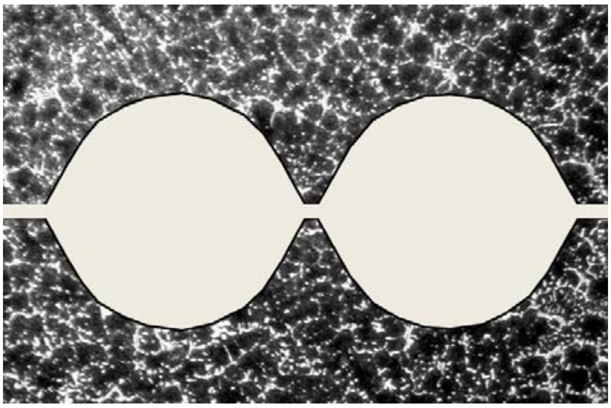

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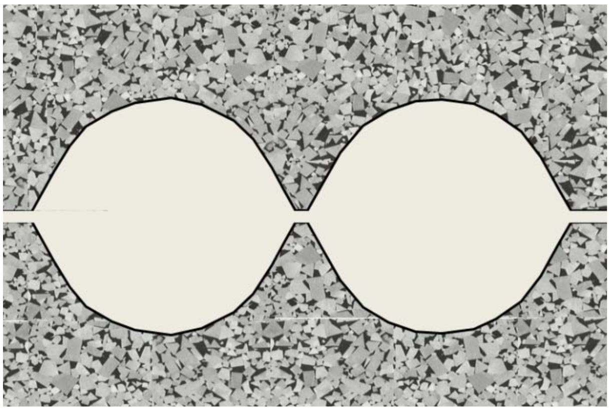

M ca. 400x

Figure 8: Microstructures in the cross section of a typical slitting pass. top: standard static cast SGA roll 75 ShC. middle: optimized spun cast HSS roll 78 ShC; bottom: cemented carbide ring 85 ShC.