THE METALLURGY AND PERFORMANCE OF ENHANCED CARBIDE ALLOY INDEFINITE CHILL ROLLS (APEX) FOR THE LATE STANDS OF HOT STRIP MILLS[1]

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Abstract
In today's modern hot strip mill, productivity, efficiency and strip surface quality are essential for long term success. For the late stands, the traditional Alloy Indefinite Chill (AIC or ICDP) roll materials work well but do have limitations in surface quality which can result in unscheduled roll changes and special cascading practices. For this purpose, Enhanced Alloy Indefinite Chill roll materials were developed which utilise optimised roll microstructures that provide uniform wear of the surface for superior strip surface quality as well as provide consistency of these properties through life. The APEX Enhanced Carbide AIC roll has proven successful for the late stands of a large variety of mill applications. The unique microstructure of APEX has proven to result in superior surface finish along with maximum resistance to crack initiation and growth. The resistance to wear of the barrel profile has also resulted in minimization of stock removals during grinding which have improved the cost effectiveness of the roll material.
Key words: Centrifugally cast rolls; Indefinite chill cast iron; Hot strip mill; Performance.

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1 INTRODUCTION

The traditional roll of choice for the late stands of hot strip mills has always been the Alloy Indefinite Chill roll (AIC or ICDP). The special microstructure and properties that AIC provides is uniquely suited to the conditions that are inherent in the late stands of hot strip mills for the achievement of good wear performance, resistance to strip adhesion and mechanical damage resistance (cracking and spalling). The standard AIC material though does have limitations which results in the need for special cascading practices, limited campaign lengths and unscheduled roll changes in order to ensure optimum strip surface quality. For this purpose, the APEX Enhanced Alloy Indefinite Chill roll material was developed which utilizes optimized roll microstructures that provide uniform wear of the surface for superior strip surface quality as well as consistency of these properties through life.

2 DISCUSSION

2.1 The Metallurgy and Limitations of Standard Aic Materials

The surface quality, wear resistance and damage resistance of Standard AIC roll materials can be directly translated from their microstructure and mechanical properties. As a basic microstructure, Standard AIC roll materials consist of a careful balance of primary carbide and free graphite in a matrix of mostly lower bainite and martensite (Figure 1). For an iron based material, it is therefore neither “white iron” or “grey/ductile” iron but a delicate mixture of the two which draws on the advantages of both types of materials.

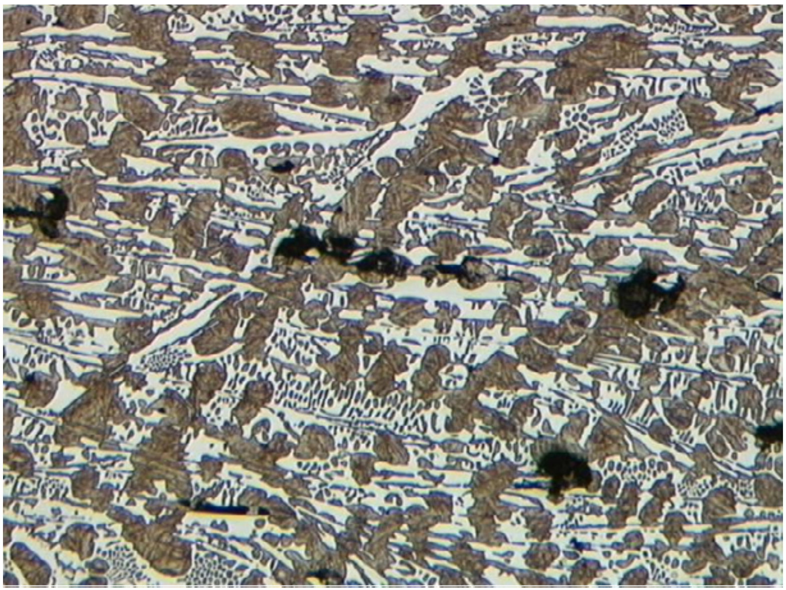

Figure1. Typical microstructure of Standard AIC – approximately 50X (2% Nital). White phase is primary M3C carbide, Brown phase is the martensitic/bainitic matrix. Black phase is the dendritically aligned compacted flake graphite.

In the later stands of a hot strip mill, the strip temperature is typically reduced to the point where it is difficult for an oxide layer to form on the surface of the roll which can assist to prevent abrasive wear.

The rolls campaign length and the efficiency of the mill itself is therefore partly dependant on how long the late stand roll materials can maintain their surface texture and profile (shape) which is directly the result of the abrasive wear resistance of the roll material.

Most Standard AIC roll materials contain somewhere between 25 – 40% primary carbide which is the principal component for the resistance to abrasive wear. The primary carbide is 100% dendritic M_3C type which is the result of the chemistry and stoichiometry of the elements present and exhibits a hardness that is higher than the matrix (up to 1100 HV compared to approximately 650-750 HV maximum hardness of the matrix).

The wear resistance potential of the Standard AIC material is therefore limited as the primary carbide is only about 50% harder than the parent matrix at best. The exact volume of primary carbide is the result of chemistry, melting practice and solidification rate used by the manufacturer and can be altered using these specifications to suit a specific mills operating conditions.

Although detrimental to wear resistance, the presence of free graphite in late stand roll materials is essential. It provides numerous benefits including lubricity in the roll bite which helps prevent the strip from adhering to the roll surfaceas well as improved thermal damage resistance. The presence of free graphite also provides a good expansion coefficient coupled with low thermal diffusivity which ensures that the thermal crown can be easily maintained between slabs for good strip shape control.

Most standard AIC rolls contain somewhere between 1 – 3% free graphite in a compacted – interdendritic form near the surface of the roll. The shape of the graphite does change with radial depth where it will become gradually more short-flake-like once past the columnar solidification zone (approximately 1/3 – 1/2 of the radial depth of the shell). The shape and quantity of graphite must be controlled as too much free graphite (especially in the flake form) could result in a differential wear pattern in the roll surface which can transfer to the strip and result in poor surface quality (this condition is known as “orange peel”).

The shape and distribution of the graphite in interdendritic compacted flake form can reduce the effective strength and ductility of the roll material by providing pathways for crack propagation. Same as with the carbide, the exact volume and shape of free graphite is the result of chemistry, melting/inoculation practice and solidification rate used by the roll manufacturer and can be altered using these specifications to suit a specific mills operating conditions.

The volume of carbide and graphite present in a Standard AIC microstructure are inversely dependant on each other meaning that as the volume of one increases, the volume of the other decreases. The balance between these phases is typically referred to as the carbide-to-graphite ratio.

The carbide-to-graphite ratio for all Standard AIC rolls is directly dependant on the chemistry, melting practices, nucleation potential and solidification rate. Of these aspects, the only one that significantly changes during the manufacturing process is the solidification rate therefore the carbide-to-graphite ratio will be highest (more carbide and less graphite) when the roll is new and will gradually decrease as the barrel diameter is consumed (Figures 2 and 3).

This higher content of graphite through the rolls life will result in a reduced hardness and reduced wear resistance and also could promote a differential wear condition (“orange peel”) once the carbide-to-graphite ratio drops below a critical value. The lower wear resistance of the rolls ultimately impact the efficiency of the mill as more frequent roll changes will be required to ensure strip shape and surface finishing is maintained.

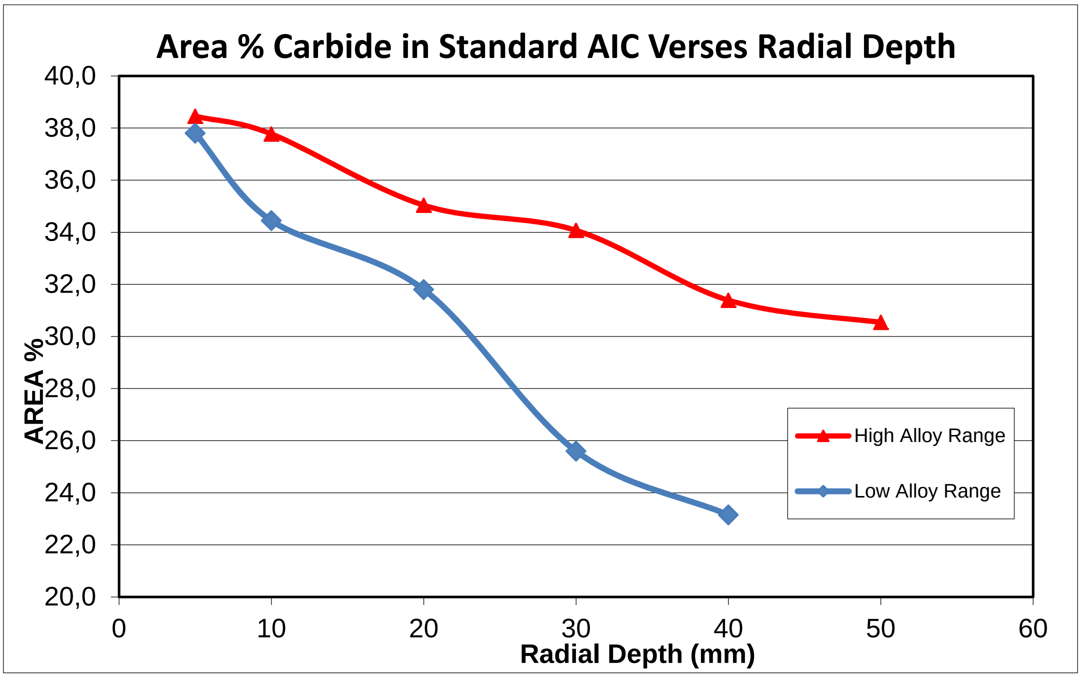

Figure 2. Standard AIC – change in carbide volume verses radial depth.

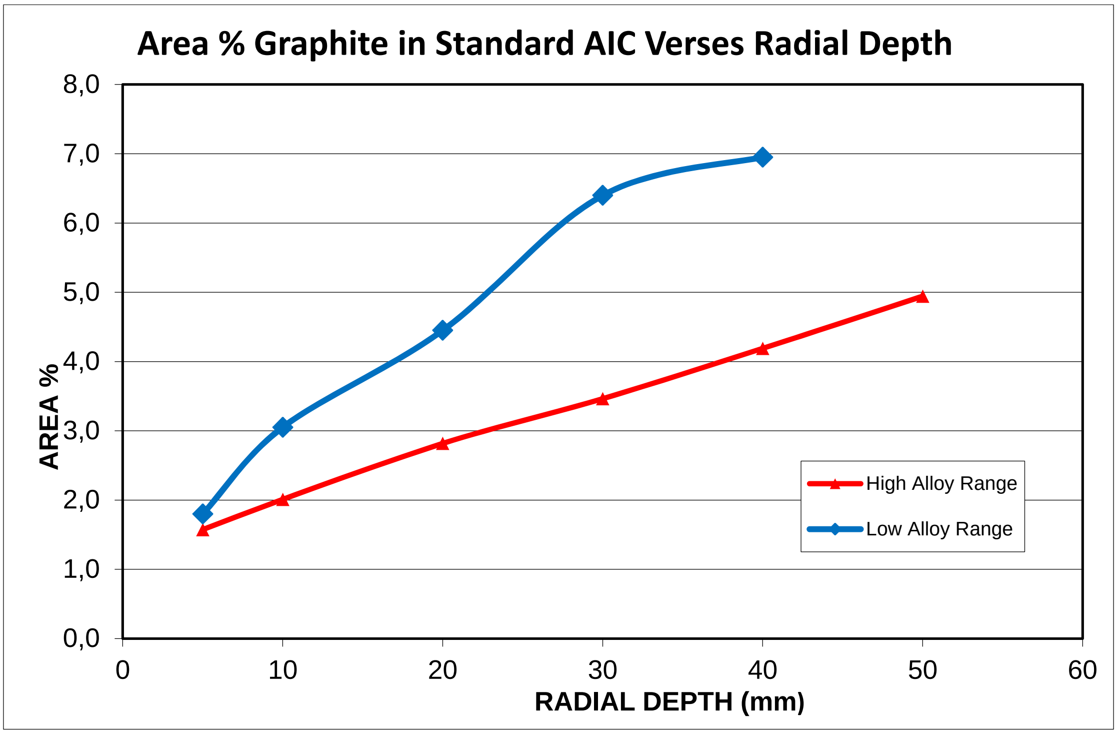

Figure 3. Standard AIC – change in graphite volume verses radial depth.

2.2 The Metallurgy of Apex Enhanced Carbide Alloy Indefinite Chill Material

To improve the overall performance of the roll and therefore the quality, efficiency and performance of the mill, the APEX Enhanced Alloy Indefinite Chill roll material was developed at UESUK in 1998 (referred to simply as APEX). The material is still in the same family of Alloy Indefinite Chill materials with the same microstructural phases present (Figure 4) but development of APEX included three key aspects which combined result in improvement to all of the issues detailed above for Standard AIC rolls:

- Introduction of a hard MC carbide.
- Spheroidization and improved distribution of the free graphite.
- Consistent microstructure and hardness through life.

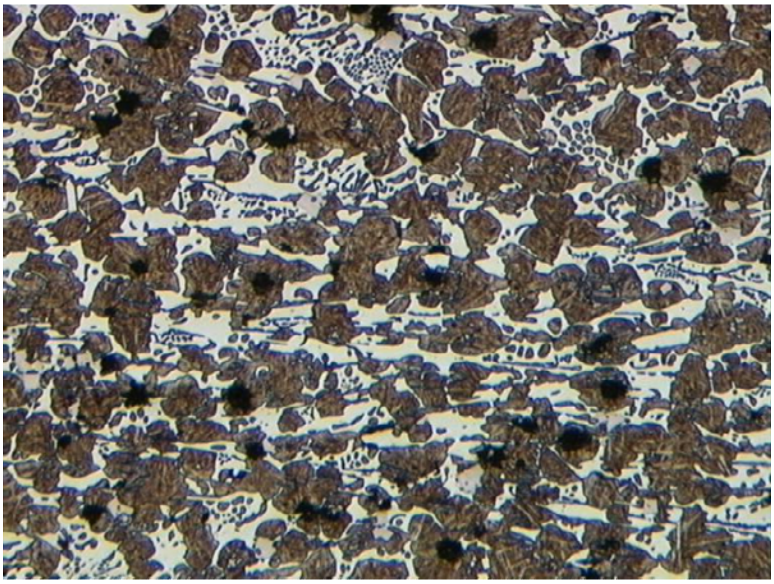

Figure 4. APEX – ECI roll material – approximately 50X (2% Nital). White phase is primary M_3C carbide -Pink phase is the enhanced, hard MC carbide. Black phase is the spheroidal and distributed graphite - Brown phase is the martensitic/bainitic matrix

The overall chemistry of APEX is fairly similar to Standard AIC except for the addition of niobium (Nb) which forms an MC type carbide that exhibits more than twice the hardness of the primary M_3C carbide, 2400 HV vs the 1100 HV maximum of M_3C type carbide. The addition of niobium is carefully controlled so that the NbC carbide that forms is very small in size (approximately 10 microns or less) and evenly distributed throughout the microstructure with a total concentration of about 1% (Figures 5 and 6). The very high hardness and even distribution of the NbC reinforces the microstructure and helps to provide improved wear resistance of the overall roll material. This improvement in wear resistance ensures the APEX roll material will maintain its profile and surface texture longer than a Standard AIC roll therefore allowing the mill to run longer before a roll change is required for strip shape or surface quality control.

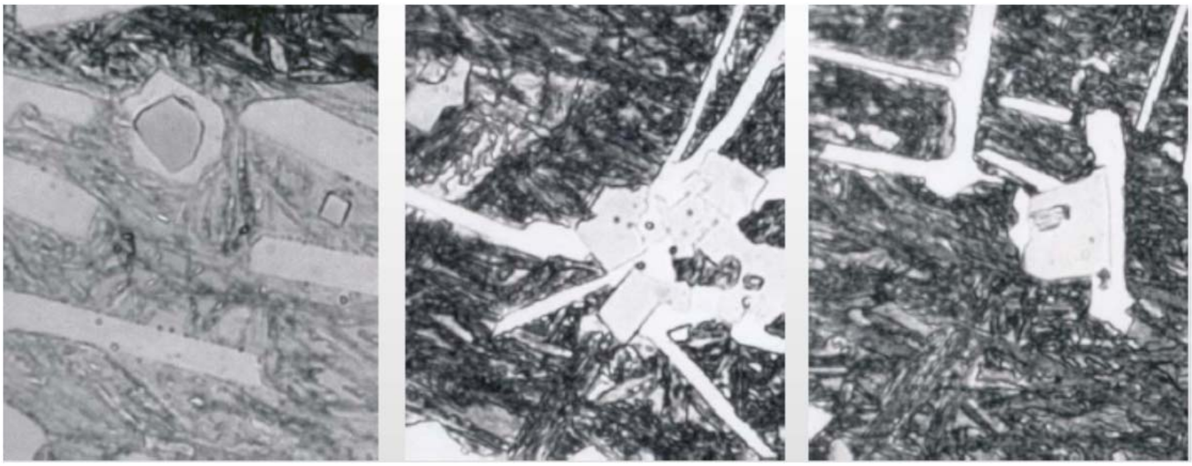

Figure 5. Close up view of the hard niobium carbide present in the APEX microstructure – approx 2000X (2% Nital).

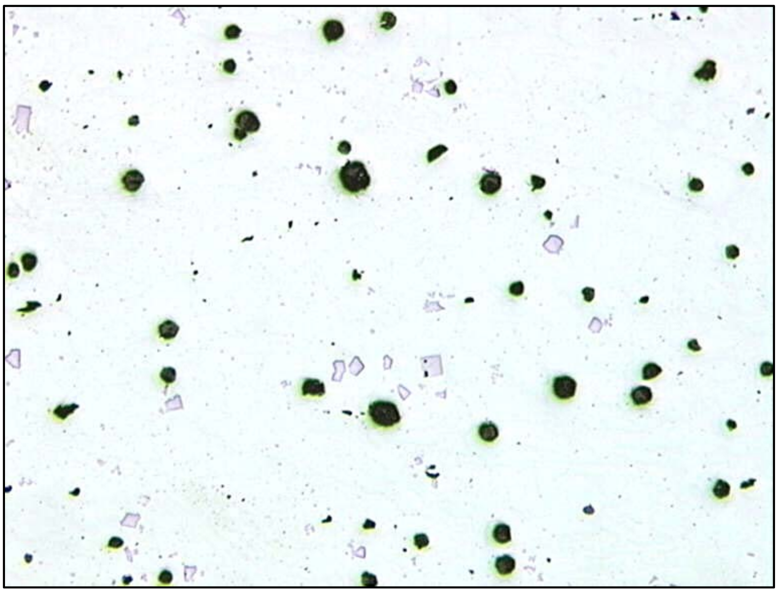

Figure 6.APEX at approximately 50X – unetched. Showing the even distribution of the hard niobium carbides (pink phase), the spheroidal shape and even distribution of the graphite phase.

A unique inoculation practice is used during the manufacture of APEX to both nucleate and spheroidize the graphite. This results in a controlled nucleation of graphite that is both spheroidal in shape, but also small and very evenly distributed throughout the matrix (Figure 6). The spheroidal shape and even distribution results in an improved strength of the roll material by 21% which improves the rolls resistance to damage (Table 1). This improvement is partially achieved by providing resistance to crack propagation by effectively “pinning” cracks rather than presenting a convenient pathway for propagation exhibited by the interdendritically aligned compacted flake graphite of Standard AIC. The overall volume of graphite in APEX is however similar to Standard AIC thus ensuring that the benefits that the graphite provides to stability of the material in the mill are maintained.

Table 1. Mechanical properties of APEX x regular AIC

	APEX	Standard AIC
Ultimate Tensile Strength (MPa)	420	345
Yield Strength (MPa)	380	300
Compressive Strength (MPa)	910	540

Even given the improved overall wear and crack propagation resistance, the biggest advantage the APEX work roll provides is the ability to maintain a uniform surface texture and the resistance of the roll surface to differential wear (orange peel).The control of the graphite shape and distribution ensures that there are no large areas or clusters of the soft graphite present which can result in a noticeable surface texture when worn away from the parent matrix and carbide. The even distribution of the very hard NbC also provides stability to the overall microstructure to help prevent preferential wear effects from the different phases present. The combined effect of the evenly distributed NbC and spheroidal graphite result in very even wear of the roll surface which provides superior roll and strip surface quality throughout the length of the rolls campaign (Figure 7). The superior strip surface quality achieved by the use of APEX material therefore ensures the reduction or complete elimination in unscheduled roll changes for strip surface texture.

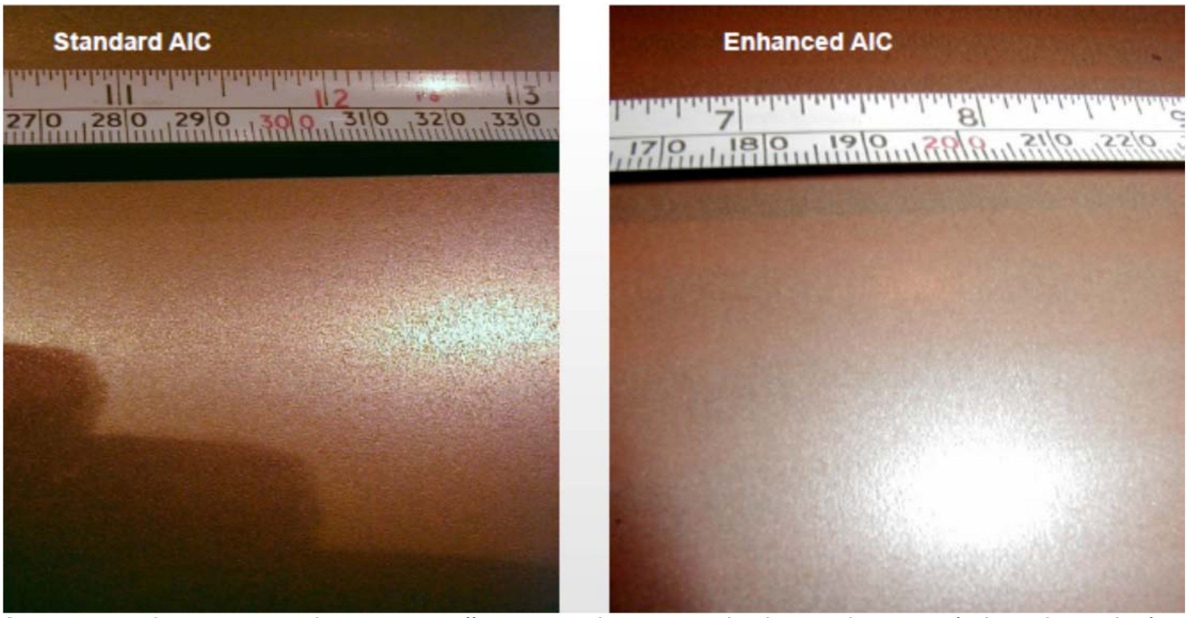

Figure 7. Surface texture of an APEX roll compared to a Standard AIC after completion of a typical campaign in the last stand of a hot strip finishing mill. The APEX roll exhibits a uniform surface finish compared to the Standard AIC which is beginning to show the first stages of differential wear (orange peel).

The other major advantage of the APEX roll material is the consistency of the microstructure and hardness through the life of the roll.
Quantitative image analysis has shown that the volume and distribution of NbC does not significantly change with radial depth from the surface of the roll as new through to the finish diameter of the roll (Figure 8), this is partly the result of the NbC formation at high temperatures when the rest of the metal is still in a liquid state.

The development of the NbC is not affected by solidification rate as is the primary M_3C carbide and is also not affected by macrosegregation effects.
The NbC is evenly distributed through the depth of the roll due to the combined effects of a fast solidification rate and density differential.

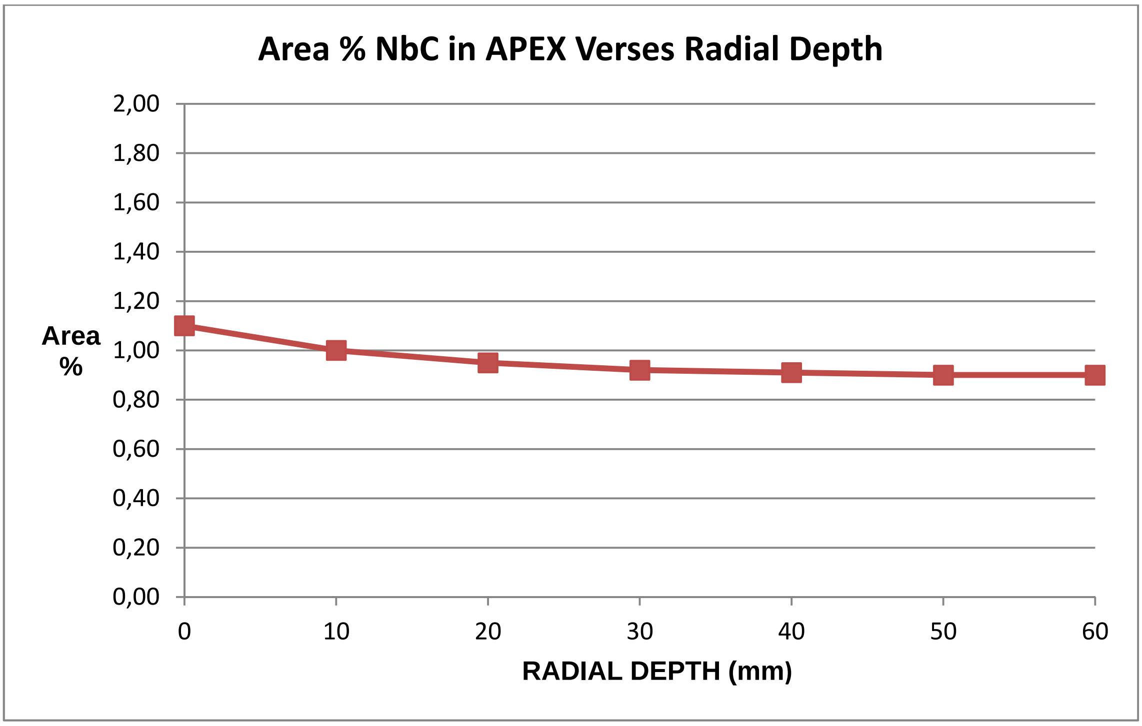

Figure 8.A PEX – change in volume of niobium carbide with radial depth through the shell.

The same control of volume and distribution through the roll life also applies to the spheroidal graphite that is present in the APEX material. The unique inoculation practice that is used to provide a spheroidal shape and uniform distribution to the graphite exhibits a very slow fade rate which ensures that these effects are present during the entire solidification process of the shell material (Figure 9). This unique inoculation practice also stabilises the carbide-to-graphite ratio which combined with the slow fade rate results in the formation of a more consistent carbide-to-graphite ratio and hardness through the entire shell cross section (Figures 10, 11 and 12).

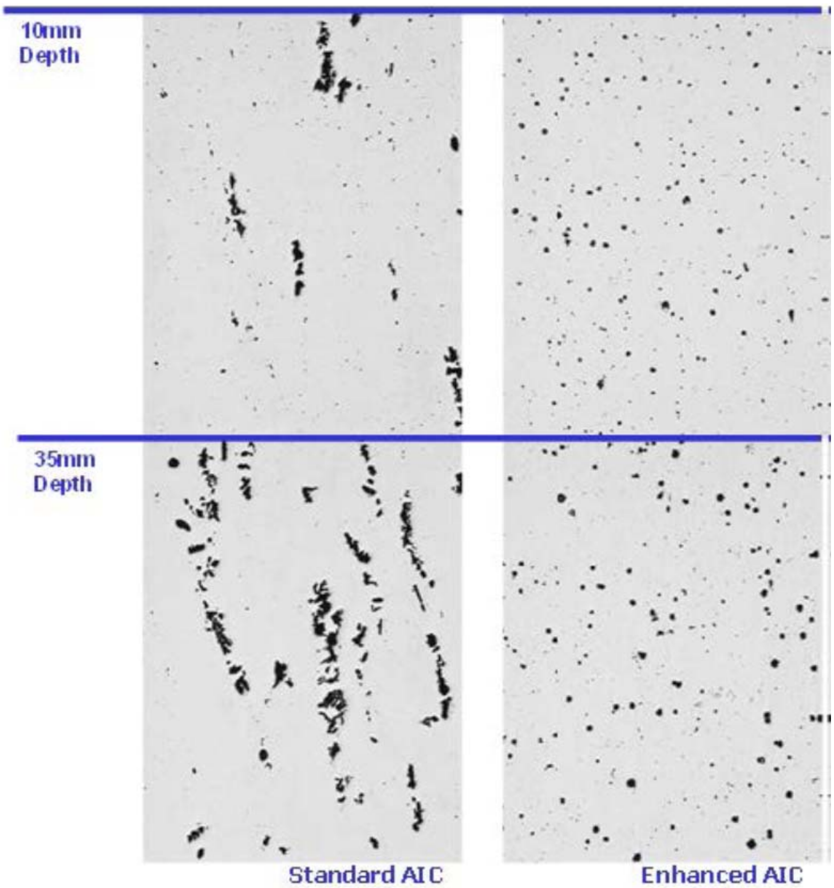

Figure 9. APEX verses Standard AIC - Change in graphite shape and distribution (Unetched).

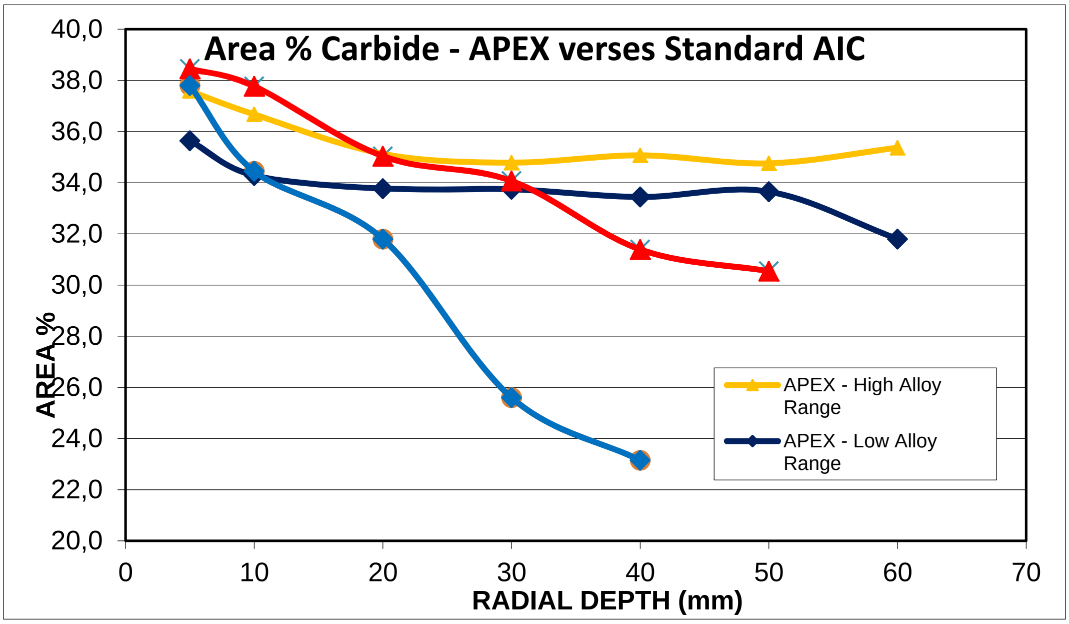

Figure 10. APEX verses Standard AIC – change in carbide volume verses radial depth APEX showing a more consistent carbide volume with radial depth.

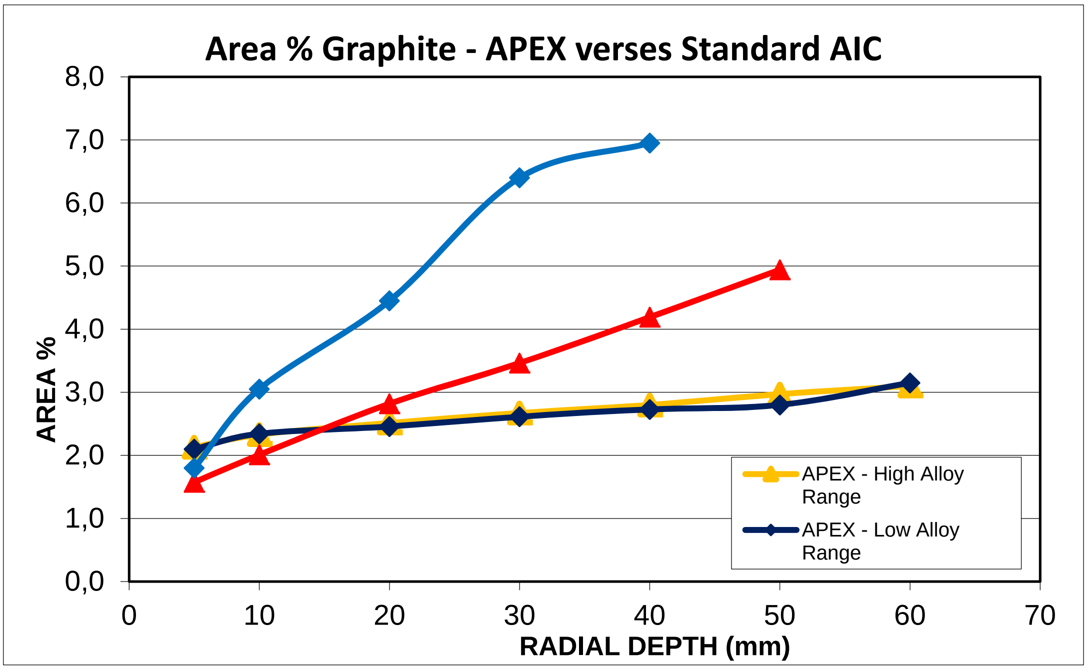

Figure11.APEX verses Standard AIC – change in graphite volume verses radial depth APEX showing a more consistent graphite volume with radial depth.

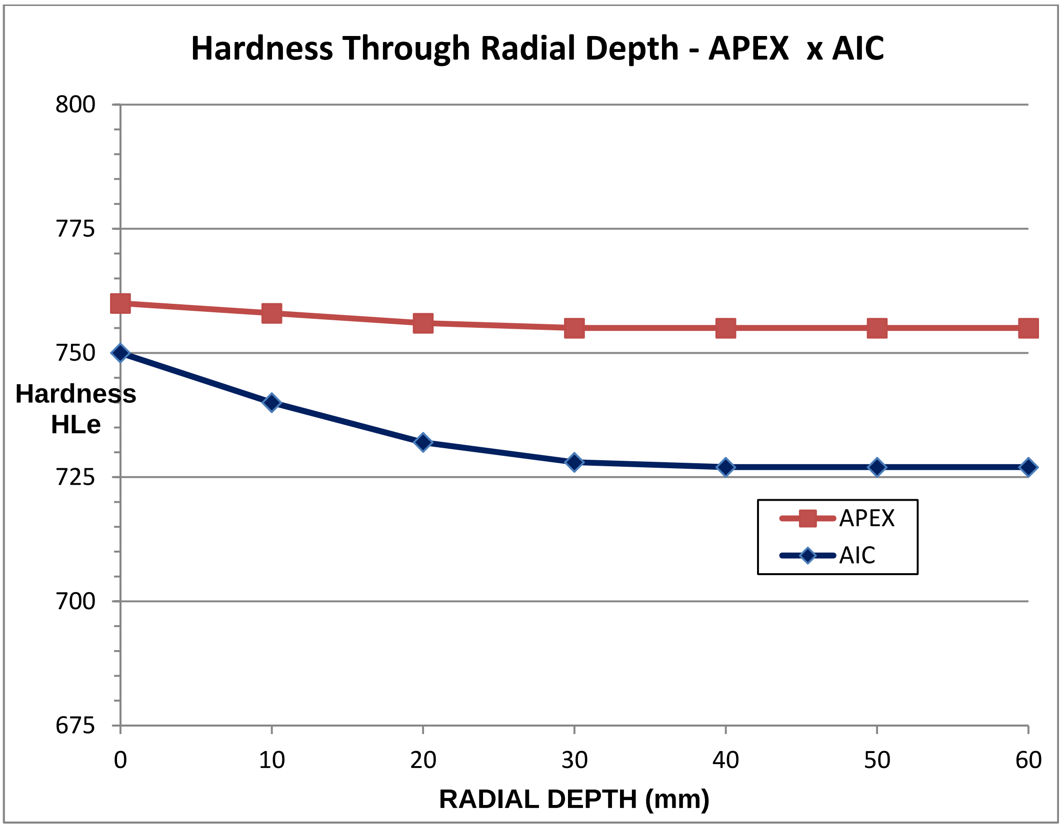

Figure12.APEX verses Standard AIC – change in hardness verses radial depth APEX showing a more consistent hardness with radial depth.

3 CONCLUSION

The combination of the control achieved with the NbC volume, graphite shape and distribution as well as carbide-to-graphite ratio through the APEX shell results in a very consistent microstructure and hardness from new diameter through finish diameter. This ensures that the performance benefits of APEX including wear resistance, surface quality, hardness, damage resistance are all well maintained through life.

To date, UESUK have manufactured greater than 5400 APEX rolls for supply to all types of hot mills including traditional hot strip finishing, continuous finishing and Steckel mills. In all applications, the APEX rolls were reported to exhibit an improved performance over the traditional Standard AIC type roll in every category. The improvements in surface quality and microstructural consistency through life have all resulted in a reduction in mill downtime for unscheduled roll changes, improvements in rolled product flexibility, extended campaign lengths which have improved mill productivity as well as provided the highest surface quality of the rolled product.

APEX rolls have also shown up to 20 – 25% improvement in tonnes rolled per millimetre of roll diameter used over the Standard AIC roll as the result of longer campaigns and reduced wear profiles. The unique microstructure of APEX roll material with refined microstructure and spheroidized and homogeneous distribution of graphite in the working shell exhibited better performance in tonnes rolled per millimetre of roll diameter than other Enhanced Carbide AIC rolls in numerous applications and mill types ensuring the highest possible mill efficiency and cost effectiveness (Figures 13, 14, 15 and 16).

The metallurgical and mechanical properties of the APEX have been proven to display superior wear performance combined to the accident resistance which results in a total outstanding total performance (t/mm). The use of APEX roll material in the late stands has therefore proven itself to only be advantageous in every respect to mill and roll shop productivity, quality and cost.

In every mill application, the key for long term success is high quality product at lower costs. One way to achieve this goal is through the improved mill efficiency, productivity and roll performance achievable with the use of APEX Enhanced Alloy Indefinite Chill work rolls in the later stands.

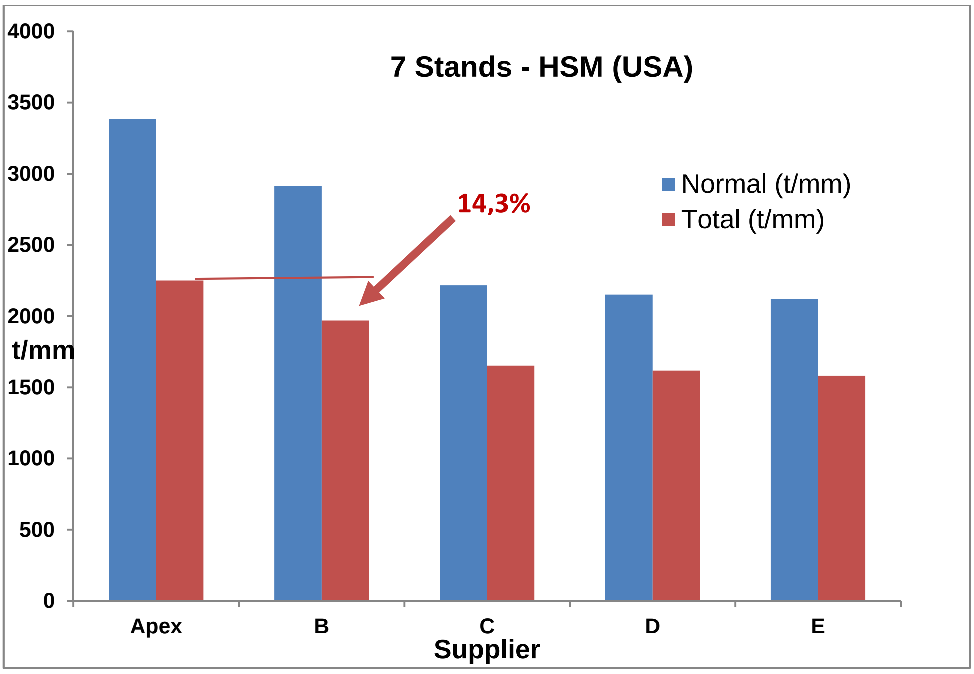

Figure 13. Performance of Apex (F5-F7 stands)- Data is from Jan/11 thru Mar/12.

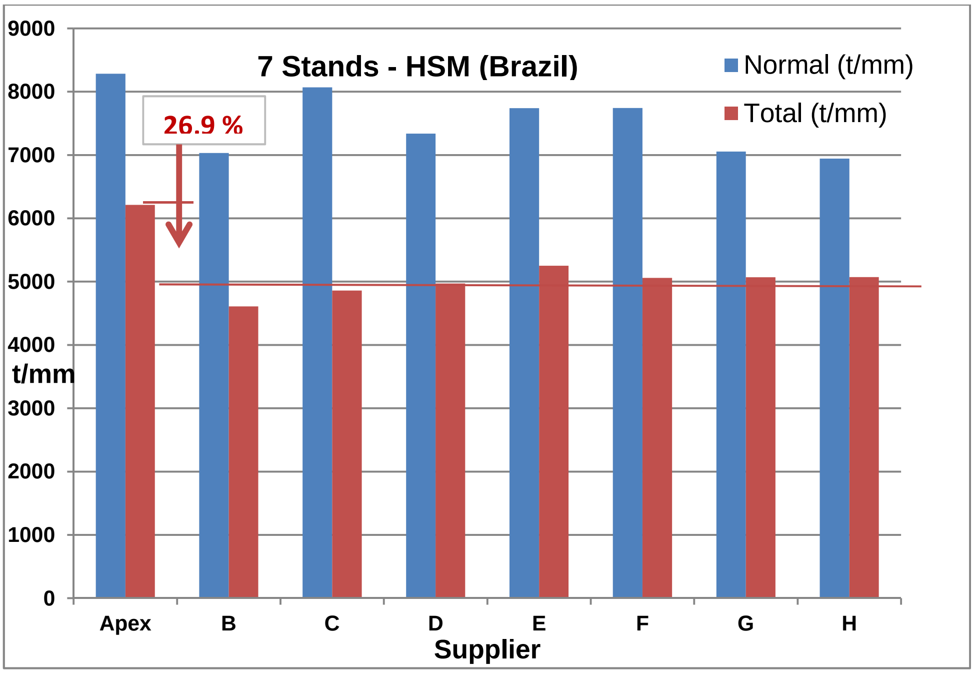

Figure 14. Performance of Apex (F5-F7 stands) – Data is from Jan/11 thru June/12.

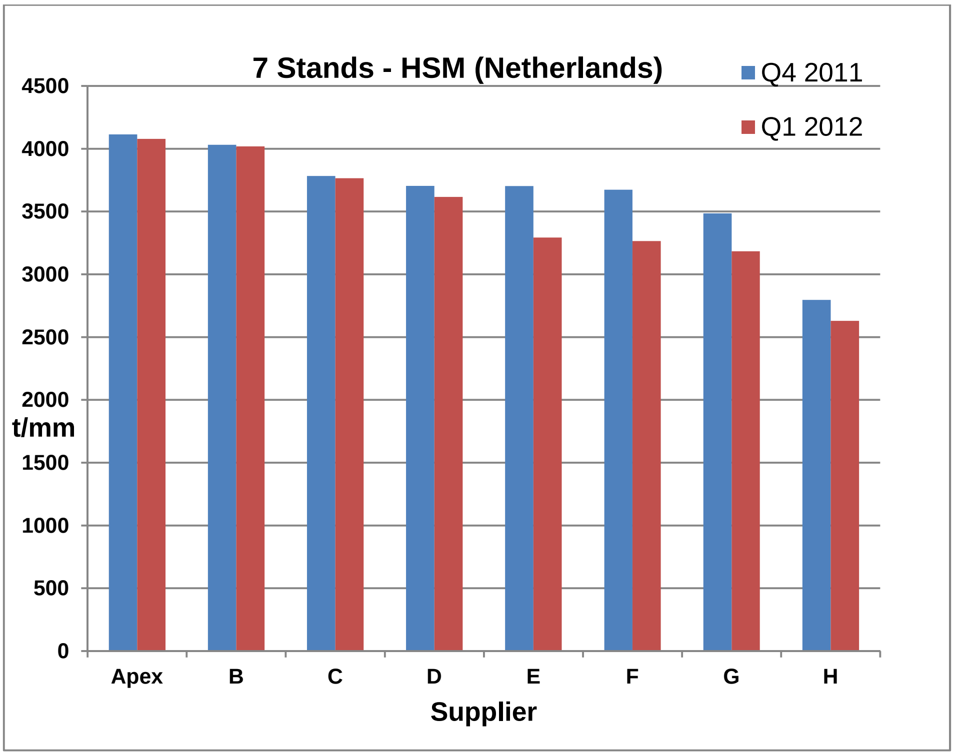

Figure 15. Total performance of Apex (F5 –F7 for a typical 7 Stand HSM.

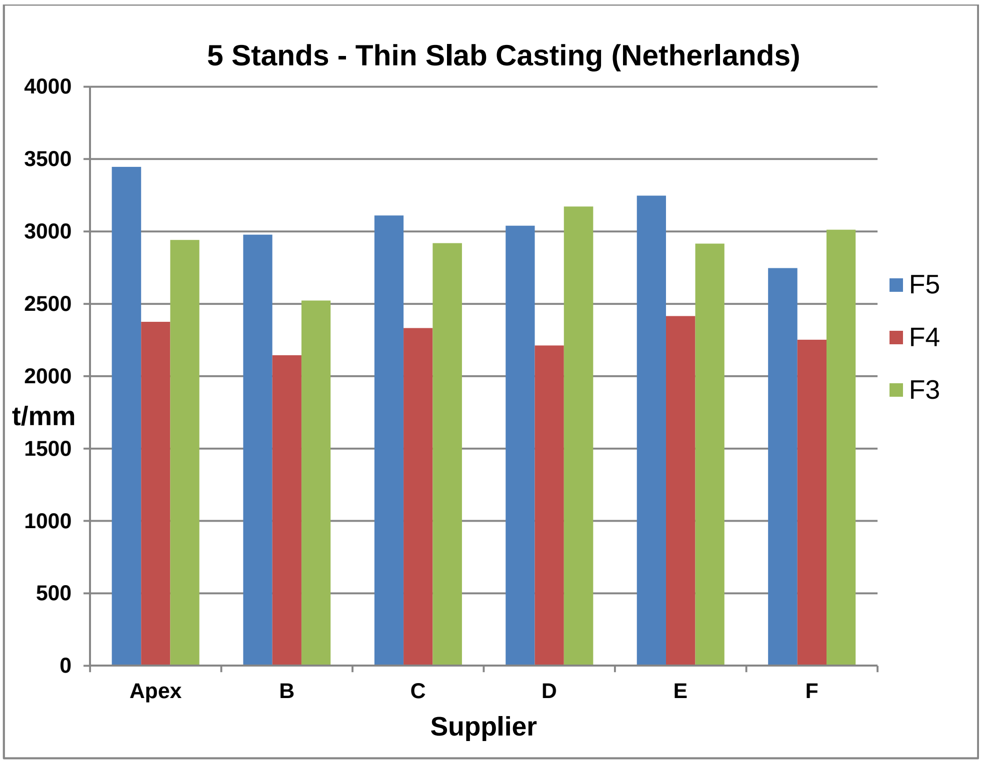

Figure 16. Performance of Apex by stand in a 5 stands compact HSM. Data is from 2011/12.