Recent Developments in Coiler Pinch Roll Technology

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ABSTRACT

Recent developments in coiler pinch roll technology include alloying of Bemcalloy C-1 gray cast iron with Niobium. The alloy additions promote increased wear resistance without negative effects on the pick-up resistance of Bemcalloy C-1 Pinch Rolls. The new technology, known as Bemcalloy C-141, has demonstrated a significant increase in lineal feet coiled per stock loss in the initial trial campaign.

KEYWORDS: Coiler Pinch Roll, Bemcalloy C-1, Bemcalloy C-141, Alloy Gray Iron, Niobium, and Hot Strip Mill Roll

INTRODUCTION

Recently, coiler pinch rolls have become more recognized as a critical component of the hot strip mill. Once considered a commodity product, pinch rolls have gained increased attention as hot strip mill productivity and the demand for quality has become more aggressive.

This article outlines the specific productivity and quality demands of the pinch roll application and how an enhanced pinch roll material, Bemcalloy C-141, has been developed to meet these increasing demands. Also included is a review of the existing Bemcalloy C-1 pinch roll material to illustrate the basis and methodology used in the development of the new technology. Trial data for the Bemcalloy C-141 technology concludes the paper.

APPLICATION DEMANDS

In order to successfully develop new, or enhance existing coiler pinch roll technology, a complete understanding of the demands of the application is essential. Coiler pinch rolls consist of a set of top and bottom rolls at the end of the hot strip mill. Their function is to receive the head end of the hot band and direct it into the coiler. These rolls can also provide a slight tension in the hot band during coiling if the top pinch roll runs engaged throughout the coiling process. This practice is primarily used to obtain better coil quality[1].

Coiler pinch rolls are the last set of rolls in the hot strip mill that the hot rolled product contacts. As such, the demands placed on these rolls have intensified with desires of increased hot mill productivity and higher hot strip quality.

An increase in hot strip mill productivity typically means that the rolls will be subject to longer hot strip lengths (larger coils), longer

[1] Coil quality in this sense refers to the "tightness" and edge straightness of the coiled product. Engaging the top pinch roll throughout the coiling process to increase coil quality has become more common, even though this practice is substantially more abusive to the pinch rolls.

campaigns, and increased tonnage over the life of the rolls. These productivity requirements imply that the pinch rolls possess resistance to wear, thermal stability, high thermal conductivity, and through-hardness. Table 1 summarizes the productivity demands and the corresponding pinch roll property requirements.

Table 1. Productivity demands and corresponding pinch roll property requirements.

Productivity Demands	Pinch Roll Property Requirements
• Long hot strip lengths	• Good thermal conductivity • Thermal stability
• Long campaigns	• High wear resistance
• High tonnage over life of roll	• High wear resistance • Through-hardness

As in all hot strip mill applications, the materials that contact the hot product must possess good thermal properties. The pinch roll application is no exception to this rule. With longer coils being coiled, and longer campaign lengths, the amount of heat generated at the surface of the pinch rolls can lead to severe surface deterioration of both the pinch rolls and the hot strip. A material with a high thermal conductivity will dissipate the heat more rapidly and thus reduce the surface deterioration and risks of friction welding. A material with a low modulus of elasticity will be less susceptible to cracking due to thermal stresses. Thermal stability refers to the ability of the material to maintain its heat-treated properties under the elevated temperatures experienced during service. A material with good thermal stability will maintain its strength and hardness at elevated temperatures and be less susceptible to softening while in service.

Two wear mechanisms, abrasive and adhesive (frictional), occur in the pinch roll application. The percentage of each of the wear mechanisms depends on the pinch roll material being used.

Abrasive wear results when a harder material removes particles from a softer surface. In the pinch roll application, the hardness of the hot strip being coiled is soft relative to the hardness of the pinch roll, and therefore, the hot strip itself does not abrasively wear the pinch rolls. However, extraneous materials (scale, mill debris, and hard particles carried by the coolant and transferred through the water sprays) invoke abrasive wear [1].

Adhesive, or frictional wear, results from the scuffing action between two surfaces that come into contact. Adhesive wear occurs when appreciable heat is generated by friction between the surfaces. Often, projecting surface asperities present on the roll and product being coiled are locally heated when the surfaces come into contact. The localized heat can cause the surfaces to gall as a result of frictional welding. Upon further relative motion, the particles tear out and produce new asperities on the roll surface [1].

Obviously the resistance to wear, either abrasive or adhesive, or both, is a direct function of the pinch roll material, its hardness, and its microstructure. However, certain mill-related variables can accelerate wear of the pinch rolls. Such variables include keeping the top pinch roll engaged throughout coiling, using unfiltered coolant, inadequate spraying of the hot strip to remove scale and extraneous debris, and improper tension control between the pinch rolls and the coiler.

The ability of a pinch roll to be through-hardened is a positive attribute when considering overall performance. A through-hardened material has a consistent hardness throughout the cross-section and thus can be used to scrap size without re-hardening, re-sleeving or welding. Also, application stresses can be more evenly distributed over the entire hardened cross-section.

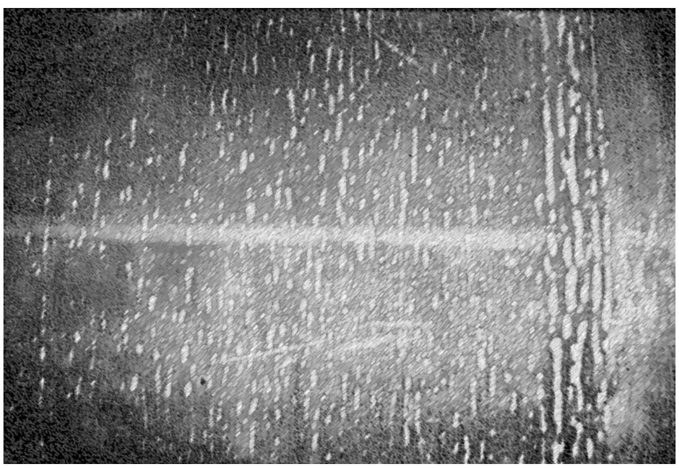
In addition to the above productivity requirements, the pinch rolls must also possess resistance to “pick-up” to ensure adequate hot strip surface quality. Table 2 summarizes the quality demands and corresponding pinch roll property requirements.

Table 2. Quality demands and corresponding pinch roll property requirements.

Quality Demands	Pinch Roll Property Requirements
• Superior hot strip surface	• Good resistance to pick-up • High wear resistance
• Tighter and straighter coil	• High wear resistance

Pick-up, as it is referred to in this text, is a condition whereby foreign material becomes adhered to the surface of the pinch roll during service. The foreign material is usually adhered metal from the actual product being rolled. Figure 1 is a photograph of a forged steel bottom pinch roll exhibiting a severe pick-up condition.

Figure 1. Pick-up on forged steel bottom pinch roll.



Pick-up on a pinch roll occurs when the product being coiled becomes fused to the roll surface due to extreme localized temperatures and pressures. When small imperfections or raised areas on the hot strip pass through the roll bite, they are subject to localized temperatures and pressures significant enough to cause them to become friction welded to the pinch roll surface. Once welded to the surface of the roll, the areas are pulled from the product as it continues through the roll bite. The pick-up material on the pinch roll surface will harden as it passes by the water sprays. As the pinch roll continues to coil, the pick-up can transfer marks on any subsequent hot strip being coiled, thus drastically degrading the surface quality of the hot strip.

The amount of pick-up that occurs is mainly a function of the pinch roll material, but is aggravated by certain mill-related variables such as poor tension control between the pinch rolls and coiler, poor surface and edge quality on the hot strip, and inadequate water-cooling of the pinch rolls.

From the previous discussion it becomes obvious that the pinch roll application requires a material that possesses a balance between the critical properties of wear resistance, resistance to pick-up, good thermal stability and conductivity, and through-hardening capability.

These application demands have brought about the extensive use of the existing Bemcalloy C-1 technology. Furthermore, the desires for even greater improvements in hot mill productivity and hot strip quality was the impetus for the recent development of the Bemcalloy C-141 technology.

EXISTING BEMCALLOY C-1 COILER PINCH ROLL TECHNOLOGY

The standard Bemcalloy C-1 material is being used successfully in many coiler pinch roll applications[2]. The Bemcalloy C-1 material is a hypoeutectic gray cast iron, alloyed with silicon, nickel, chromium, and molybdenum. The selected alloys are present within the gray iron at levels that provide a balance between carbide formation and graphitization.

The chemistry contains enough alloy to allow for through-hardening of the standard wall thickness of the sleeves used in top and bottom pinch roll designs. The composition and microstructure dictate the properties of the heat-treated Bemcalloy C-1 material. A microstructure representative of one that is found in a Bemcalloy C-1 pinch roll is shown in Figure 2.

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[2] A recent survey shows that Bemcalloy C-1 top pinch rolls occupy 50% of domestic mini hot strip mills and 70% of integrated hot strip mills [2].

Figure 2. Representative photomicrograph (250X) of heat-treated Bemcalloy C-1 pinch roll material.

The microstructure shown above was achieved through controlled cooling after centrifugal casting and subsequent oil quench and tempering. The hardness is 62 HSC (approximately 46 HRC)[3]. The microstructure consists of flake graphite (darkest gray constituent), discontinuous primary ferritic carbides (white constituent), and a tempered martensitic matrix. Per ASTM A-247, the microstructure of graphite is classified as mostly VII A5 [3].

Although each of the constituents of the microstructure affects all of the properties, each affects certain properties more than others do. The amount of graphite, the length of the flakes, and how they are distributed in the matrix directly influence the thermal stability and pick-up resistance, but contribute little to the strength or hardness [1]. The metallic matrix in which the graphite is distributed provides the basic strength and hardness of the Bemcalloy material. The wear resistance is aided by the natural lubricity of graphite, but is more a function of the metallic matrix and carbide content and distribution [4].

[3] The HRC value here is converted from HSC using accepted hardness conversion tables and is listed here for reference purposes only. Due to the heterogeneity of cast iron, a more accurate hardness is obtained with a Sclerescope (HSC) or Brinell (HB) instrument.

The Bemcalloy C-1 material, when centrifugally cast and heat-treated properly, will possess a microstructure consistent with that shown in Figure 2 above. In turn, this microstructure establishes the properties that enable the Bemcalloy C-1 material to perform well in the pinch roll application.

EMERGING BEMCALLOY C-141 COILER PINCH ROLL TECHNOLOGY

During the development of the Bemcalloy C-141 technology, the main criterion was to improve the wear resistance of the Bemcalloy C-1 material without jeopardizing the resistance to pick-up or other critical properties. The ultimate choice of alloying the existing Bemcalloy C-1 material with Niobium met this criterion.

Other methods could have been successfully used to increase the wear resistance of the Bemcalloy C-1 material. However, these procedures (which included increasing the hardness and/or increasing the amount of primary ferritic carbides in the material) would have negative effects on other properties as described below.

In general terms, wear resistance improves with increasing hardness. The hardness is a function of the metallic matrix of a material. It seems logical that increasing the hardness of the Bemcalloy C-1 material would increase the wear resistance. While this is true, two main factors limit the level of hardness that can be used in the pinch roll application. First, an increase in hardness would require a lower tempering temperature to be used during manufacturing. In service, the amount of heat generated at the surface of the pinch roll could approach this temperature and thus the pinch roll would be more susceptible to softening. Second, an increase in hardness would have adverse effects on the toughness of the material, and consequently the pinch roll would be less resilient to impact loading.

The wear resistance of the Bemcalloy material could have been improved by increasing the amount of primary ferritic carbides in the matrix. Increasing the cooling rate after centrifugal casting can increase the amount of primary ferritic carbides. However, the ferritic carbides are often present at the eutectic cell boundaries. A high concentration of the ferritic carbides at the boundaries would also decrease the overall toughness of the material by promoting brittle fracture along the boundaries under impact loading.

In contrast to the above methods, Niobium was selected as the alloying element to increase the wear resistance. Niobium has the ability to form hard, primary carbides that do not form at the eutectic cell boundaries and, therefore, do not have a negative effect on toughness. Also, Niobium when used as an alloying element in gray iron has been found to reduce the size of the eutectic cell, thereby increasing strength [4].

Furthermore, Niobium also has advantages over other strong carbide formers because it does not significantly affect the inoculation process [4]. During inoculation, non-Niobium metastable carbides are formed, which upon decomposition provide free carbon to nucleate graphite. Some carbide formers dissolved in the melt during inoculation may decrease the power of the metastable carbides to nucleate graphite. In the case of Niobium, however, this problem is not critical since at usual inoculation temperatures most of the Niobium is already combined as primary Niobium carbides. Any Niobium remaining after solidification will remain as a solute or precipitate out in the solid state as Niobium carbide. Consequently, the formation of graphite (necessary for pick-up resistance) is unaffected.

After the primary stages of processing, the Bemcalloy C-141 material is processed similar to the Bemcalloy C-1 material. The heat treatment process of oil quench and tempering is used to produce a microstructure similar to that of the Bemcalloy C-1 material with the only variances being a slightly refined (smaller) eutectic cell and the presence of highly dispersed Niobium carbides throughout the tempered martensitic matrix.

A representative Bemcalloy C-141 pinch roll microstructure is shown in Figure 3.

Figure 3. Representative photomicrograph (250X) of heat-treated Bemcalloy C-141 pinch roll material.

As in Figure 2, the microstructure was produced via oil quenching and tempering. The hardness is 62 HSC. The dispersed Niobium carbides are highlighted with dark arrows.

The Niobium carbides in the tempered martensitic matrix are responsible for the increased wear resistance of the Bemcalloy C-141 material. The niobium carbides provide increased wear through two ways. First, they resist abrasion due to their extremely high hardness. Second, during service, the Niobium carbides can adjust in the relatively softer martensitic matrix so as to distribute the load more evenly across the entire surface, thus minimizing the possibility of dislodgment.

In addition to the Niobium carbides that facilitate the wear resistance, the other properties of the Bemcalloy C-141 material are effected by the remainder of the constituents in the microstructure. The flake graphite is present to provide thermal stability and natural lubricating characteristics that provide the resistance to pick-up. The tempered martensitic matrix contributes to the overall strength and toughness, as well as providing an increased hardness for resisting wear. Furthermore, the Bemcalloy C-141 material maintains the through-hardening capability, excellent thermal conductivity and thermal stability.

It is this microstructure -- a product of the overall composition, primary processing techniques, and heat treatment methods -- that makes the Bemcalloy C-141 material capable of meeting the increasing productivity and quality demands of the coiler pinch roll application.

IN-SERVICE DATA

The preliminary performance data for the Bemcalloy C-141 pinch roll material show significant improvements over existing pinch roll technologies.

A Bemcalloy C-141 top pinch roll showed significantly improved wear resistance over existing pinch roll technologies as measured by lineal feet rolled per stock loss. As expected, the Bemcalloy C-141 demonstrated a resistance to pick-up consistent with that of the Bemcalloy C-1 material. Table 3 summarizes the performance results of the initial campaign of the Bemcalloy C-141 top pinch roll, as compared to the average of existing technologies through several campaigns.

Table 3. Performance results of various top pinch roll technologies.

Technology	Lineal Feet Coiled / 0.001" Stock Loss	Pick-up
Carburized	54,371	Significant
Bemcalloy C-1	57,526	Minimal
Bemcalloy C-141	83,604	Minimal

The Bemcalloy C-141 material used in the trial top pinch roll was processed as described above and used in service at a hardness of 62 HSC. The data for the Bemcalloy C-1 technology includes pinch rolls in the hardness range of 62-65 HSC. Although the Bemcalloy C-141 technology has not yet been applied to bottom pinch rolls, a performance improvement consistent with those for top pinch rolls would be expected.

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