Evaluation of the Microstructure and High Temperature Wear Behavior of Cast Iron/Tungsten Carbide Surface Composite for using in Rollers

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Abstract

Roller tables, rollers, and pinch rolls are widely used in rolling mills, sheet metal works, and ceramic and tile production industries where harsh working conditions, like heating furnaces with high temperatures, oxide debris, and ceramic materials, have been a matter of concern. High wear-resistant cast iron is a common material for manufacturing these tools. The present study evaluates the production of cast iron-based matrix surface composites reinforced with tungsten carbide (WC) as a surface metal matrix composite (SMMC) using a centrifugal casting process. To that end, the sample microstructure was characterized using optical microscopy (OM) and scanning electron microscopy equipped with energy dispersive X-Ray spectroscopy (SEM-EDX). A 3-mm thick composite layer was formed on the sample surface. Within the composite layer, WC particles were homogeneously distributed in the pearlitic and iron carbide matrix, significantly increasing surface hardness. The wear behavior of fabricated SMMC was evaluated against base metal samples produced under similar conditions: ambient temperature (25 °C) and the average roller temperature in the furnace under normally applied loads of 100, 150, and 200 N (450 °C). The formation of a composite structure on the surface dramatically improved the wear resistance of cast iron, thus decreasing the weight loss of composite samples by 61% after a 1000 m sliding distance at 25 °C compared to non-composite samples. The production of cast iron-based matrix surface composite reinforced with WC using centrifugal casting, as a feasible and acceptable process, could be a promising and cost-effective solution to improve the performance of rollers in rolling lines and even hot rolling mill rolls.

Keywords: Cast iron-based surface metal matrix composite, Tungsten carbide, Centrifugal casting, High-temperature wear.

1. Introduction

The use of cast-iron-based metal matrix composites (MMCs) reinforced with ceramic or metal carbide particles has grown considerably due to their superior properties, including high strength, high melting point, good thermal stability, suitable fatigue resistance, and excellent corrosion and wear behavior. Based on the literature, these advanced materials can effectively improve industrial parts' performance and service life, hence their widespread application in metal-forming, mining, chemical, aerospace, and automotive industries [1-5]. More recently, the material's surface has been modified through the homogeneous embedding of a secondary reinforcing phase, leading to developing of a novel group of MMCs—surface metal matrix composites (SMMCs). Generally speaking, in SMMCs, the volume fraction of the reinforced phase continuously decreases from the surface to depth, allowing the achievement of a non-uni-

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formly controlled microstructure. Such microstructure gives rise to outstanding and different properties for the material surface. Therefore, the design and manufacture of SMMCs have been extensively proposed as an effective and low-cost approach to promoting the properties of conventional materials where the surface of the parts is of great importance. In this regard, various methods, namely physical vapor deposition (PVD), chemical vapor deposition (CVD), laser cladding (LC), and thermo-reactive deposition and diffusion (TRD), have been used to fabricate the SMMCs [6-9)].

It was reported that, in MMCs, the main characteristics of the secondary reinforcing phase, including their type, amount, size, shape, and distribution, play a vital role in their performance [10,11)]. In recent years, ceramic particles, particularly Al_2O_3, TiC, SiC, TiB_2, and WC, have been extensively used in MMCs as a secondary reinforcing phase [14-12)]. Among them, tungsten carbide (WC), due to the high melting point, significant hardness, low thermal expansion coefficient, low friction coefficient, and good wettability with molten metal, is of great interest as a potential candidate for use in Fe-based SMMCs to improve their wear resistance [4-5-7-15)] .In this regard, there was evidence that WC-reinforced Fe-based SMMCs exhibited wear resistance equal to that of cementite carbide, while surprisingly, their impact toughness was 4 to 8 times higher than that of cementite carbide [16)]. Zhou et al. reported that the amount of WC particles was the essential factor affecting the wear behavior of Fe-based MMCs. It was demonstrated that the wear rate of WC-reinforced Fe-based MMCs produced by the vacuum infiltration casting decreased to the lowest value with an increase in the volume fraction of WC up to 36%, and then increased, which can be attributed to the significant decrease in matrix phase surrounded the WC particles [11)]. Most production methods of SMMCs, generally based on the deposition of a layer of reinforcing material on the substrate surface, are expensive and complex, making them less suitable candidates for use on an industrial scale. In recent years, centrifugal casting has been proposed as one of the low-cost and practical methods to produce SMMCs [1-3-17)]. Niu et al. successfully produced the WC-reinforced cast iron-based SMMCs using centrifugal casting. They observed that the reinforced specimen exhibited much higher wear resistance than the unreinforced specimen [1-2)]. Another study evaluated the wear behavior of a Hadfield steel/WC surface composite produced by centrifugal casting. The results indicated that a composite layer with a thickness of ~ 0.3 mm was formed during centrifugal casting, eventually enhancing the wear resistance of the Hadfield steel [18)]. In addition to the reinforcing material characteristics, the operational parameters of the centrifugal casting process, such as casting speed and mold diameter, play an influential role in the quality and performance of the composite layer formed on the material's surface. The investigation of the effects of centrifugal casting speed on the wear behavior of the Fe-C/WC composite showed that with increasing casting speed, the thickness of the composite layer decreased and the volume fraction of the reinforcing phase in the thin composite layer increased. As a result, the hardness and wear resistance of the composite layer improved [16)].

Many industrial parts are subject to wear, especially at high temperatures, which is one of the important reasons for their destruction. Therefore, finding strategies to improve wear resistance, increase service life, and minimize repair costs of such industrial parts has always been an interesting topic for researchers. Research shows that SMMCs can be a suitable replacement for common materials vulnerable to high-temperature wear. For instance, Song et al. compared the high-temperature wear behavior of a WC-reinforced iron matrix composite and high-speed steel produced using centrifugal casting. The finding revealed that the wear rate of the composite at 400 °C was 2.9 times lower than that of the high-speed steel [19)]. However, there is a gap in the literature regarding the research on the high-temperature wear behavior of SMMCs.

Rolls used in rolling mills, as essential equipment in the steel industry, are strongly exposed to high-temperature wear-induced damage. Accordingly, the leading manufacturers continuously seek novel and cost-effective solutions to improve the performance of their production rollers. Since a wear-resistant surface layer with an inner matrix with sufficient ductility is required for optimal roller performance, the WC-reinforced cast iron-based SMMCs can be a promising option for roller manufacturers [20)]. Accordingly, the present study investigated the wear behavior of these SMMCs reinforced with WC particles produced using centrifugal casting to produce rollers on an industrial scale in the Chodansazan Industrial Co. (CSROLL). To do so, in addition to microstructural and mechanical investigations, the wear behavior of the samples was accurately evaluated at the ambient temperature and 450 °C under loads of 100, 150, and 200 N.

2. Experimental methods

In the present study, the cast iron melt was prepared using a medium frequency induction furnace with a capacity of 400 kg from selected cast iron scrap and ferroalloys. The chemical composition of the melt was analyzed using the DFS 500 spectrometer according to the ASTM E415 standard (Table 1). To produce the SMMCs, WC-3 wt.% Co particles with a particle size of 90-1000 mm in a weight ratio of 4% were continuously added to the molten cast iron during centrifugal casting. A schematic of the cast iron/WC SMMCs production process is depicted in Fig. 1. The pouring temperature of molten cast iron was in the range of 1370-1380 °C in all experiments, and the centrifugal speed was considered constant throughout the casting process.

Samples were taken in an axial direction and etched with 2% Nital for microstructural examination. The microstructure of cast samples was characterized using Nikon optical microscopy (OM) and the Leo VP 436 scanning electron microscopy (SEM) equipped with energy-dispersive X-ray spectroscopy (EDS).

The hardness of the samples was measured using the Koopa Pajoohesh Hardness Tester with Vickers indenter following the ASTM E92-82 standard. The hardness tests were performed at a load of 500 g. The ball-on-disk type wear test was used to investigate the wear behavior of the cast samples according to ASTM G99-05. The wear tests were performed under normal loads of 100, 150, and 200 N at different temperatures (25 and 450 °C) with an alumina ball (10 mm in diameter). In all wear tests, the sliding speed and sliding distance were 0.2 m/s and 1000 m, respectively. The wear track surface was evaluated using the OM, SEM, and EDS methods to detect the wear mechanism. The specific wear rate was calculated using the following equations [15-21]:

$$K = \frac{\Delta M}{\rho L F_n} \left(\frac{mm^3}{N.m}\right) \quad (1)$$

where ΔM is the amount of weight loss for each specimen (mg), ρ is coating density (gr/cm3), and L and Fn are wear distance (m) and the applied load (N).

3. Results and discussion

3.1. Microstructural characterization of the cast samples

Fig. 2 shows the OM and SEM images of the microstructure of the unreinforced cast iron sample. The microstructure consisted of a pearlite matrix with a continuous network of iron carbide (represented by arrows in Fig. 2(b)). The high cooling rate prevented carbon precipitation in the form of graphite flakes. Indeed, the dissolved carbon in the molten cast iron is present in the form of a carbide network rather than graphite owing to the high cooling rate. It was reported that the intercellular pearlite/carbide network microstructure increased hardness, consequently improving the wear resistance of cast iron samples [22]. By controlling the solidification rate (cooling rate), a core/shell structure can be achieved where a carbide network is formed at the surface layer of the sample due to the high cooling rate. This is while at the sample's core, a low cooling rate results in the nucleation and growth of graphite clusters. Such a core/shell structure makes it possible to achieve beneficial properties for rollers used in rolling mills in such a way that the former is responsible for improving wear resistance, and the latter enhances the ductility. However, in the present study, the sample microstructure was the same from surface to core due to the high cooling rate.

The cross-sectional images of the SMMCs sample produced by centrifugal casting are shown in Fig. 3. The thickness of the surface composite layer was 3 mm, and WC particles were almost homogeneously distributed. This is expected to be able to give rollers a desirable performance on an industrial scale. The selected melt temperature ensured that the WC particles would not melt during the casting process. Accordingly, the accumulation of unmelted WC particles in the surface composite layer during the centrifugal casting can be attributed to two factors: First, the difference between the density of WC (~15.6 gr/cm3) and cast iron (~7.2 gr/cm3) that causes the WC particles to be more affected by centrif-

Table 1. Chemical Composition of the Molten Cast (All in Weight Percentage).

Element	Mg	Ni	Mo	Cr	Mn	Si	C
%	0.045	2.35	0.65	0.25	0.55	1.77	3.15

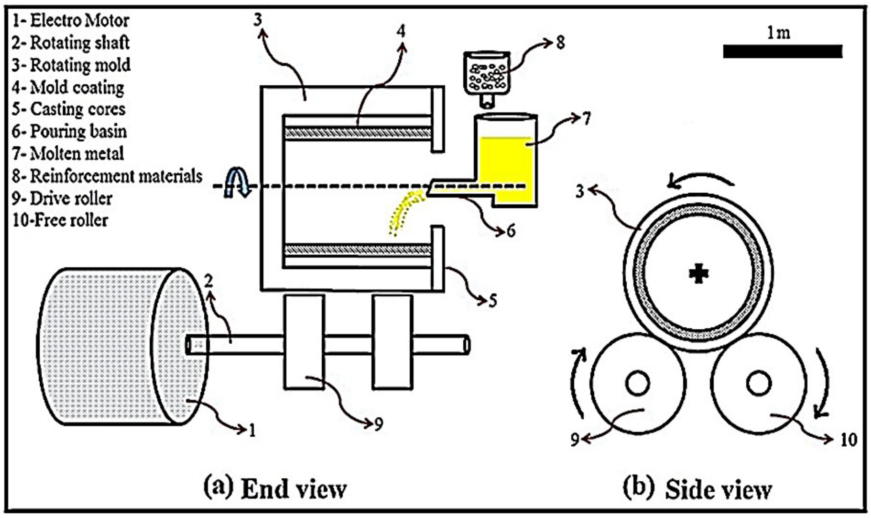

Fig. 1. Schematic of the Centrifugal Casting Process Used to Produce the Cast Iron/WC Smmcs.

ugal force [13]. Second, the high solidification rate prevented a uniform distribution of WC particles throughout the sample. Consequently, the microstructure of a cast sample can be divided into the surface layer, a composite structure consisting of a cast-iron matrix and uniformly distributed WC reinforcing particles, and the interior zone, the common structure of cast iron under rapid solidification rate (a pearlite matrix with a continuous network of iron carbide). This structure could be evidence of the successful production of WC-reinforced cast iron-based SMMCs using the industrial and simple centrifugal casting process. The resulting structure may be a desirable and practical structure for rollers because the surface structure results in excellent wear behavior, and the internal structure provides acceptable toughness, preventing the failure of the sample due to the axial force, one of the most important forces affecting the life of the rollers. As a result, the composite layer formed in the present study was thicker (cast iron/WC composite layer thickness ≈ 3 mm) than the composite coatings produced by laser cladding (for example, the Fe/TiC composite coating with a thickness of around 1 mm [23]) and thermal sprayed Ni/WC composite coating with a thickness of 2 mm [24] This decreases the production process time and the cost and provides a longer service life for this coating compared to thinner coatings during the rolling operation.

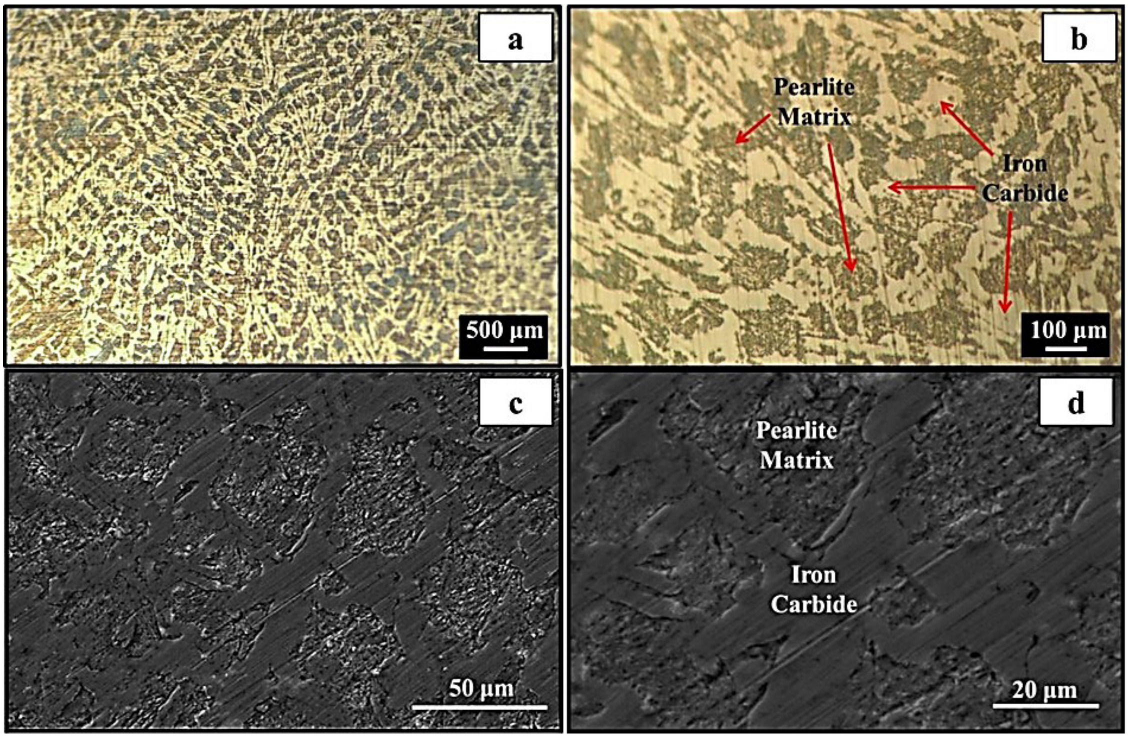

Fig. 2. (a and b) OM Images and (c and d) SEM Images of the Microstructure of the Unreinforced Cast Iron Samples.

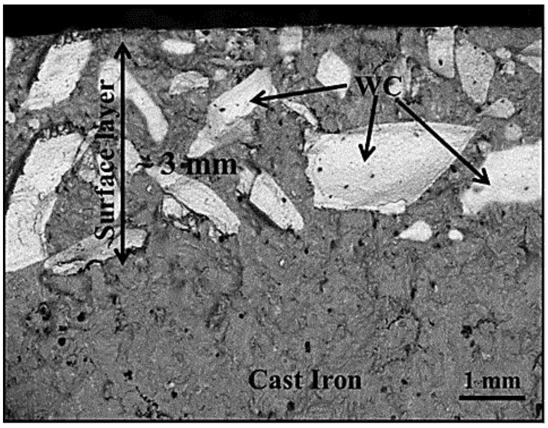

Fig. 3. Cross-Sectional Images of a Cast Iron/WC SMMC Indicating the Formation of a Composite Surface Layer with a Thickness of About 3 mm.

The OM images of the surface layer microstructure are shown in Fig. 4. Fig. 5 shows the SEM images of the microstructure of the WC-cast-iron surface composite layer, which agree with the results of the OM analysis. As described earlier, the WC particles were well and uniformly embedded in the cast iron matrix in this composite layer. Based on image analysis (Fig. 4 (a)), it can be estimated that the volume fraction of WC particles in the composite layer was 20%. Fig. 5 indicates that the microstructure of a composite surface layer consists of a pearlite matrix, a continuous network of iron carbide, and uniformly distributed WC reinforcing particles. Fig. 5 (b) indicates the magnified SEM image of a single WC particle, interestingly revealing that each large WC particle was composed of many small primary WC particles with a mean particle size of about 5–10 mm, which were well aggregated with each other. Moreover, it can be observed that the reinforcing particles were efficiently embedded into the cast iron matrix, strongly bound with the matrix. There were no gaps and discontinuity at the matrix/reinforcing particles interface, which can be attributed to the good wettability of WC particles with the molten cast iron. Strong bonding between the WC particles and the cast iron matrix was expected to improve the composite sample's mechanical properties, such as its hardness, wear resistance, and toughness. Indeed, it can be argued that the higher the interfacial bonding strength, the higher the load-bearing, and the more uniform stress distribution, which in turn prevents crack propagation into the sample. As mentioned, the phase, particularly its wettability, plays a vital role in forming a more integrated composite structure. Bao et al reported that the weak wettability of Al_2O_3, as a reinforcing phase with molten iron, as well as the difference in their coefficient of thermal expansion, led to poor interfacial bonding[25]. The WC/Fe matrix interface and the separation of WC particles from the matrix dramatically decrease the mechanical properties of the composite. The present results indicated that the WC particles exhibited good performance in this respect, which can be considered a favorable reinforcing phase for manufacturers. Undoubtedly, in addition to the intrinsic characteristics of WC particles, such as chemical composition and surface topography, the chemical composition of cast iron, as a matrix, is also essential in determining the wettability behavior. It was demonstrated that the presence of Cr and Si in the chemical composition of cast iron could significantly improve the wettability with their positive effects [4]. However, during the casting process, the absence of any reaction between WC reinforcing particles and the cast iron melt was clear (see Fig .5 (c)), while in the production of the WC/Fe metal matrix composite using spark plasma sintering, a ring of the brittle phase M6C (M = Fe, W) was formed around the WC reinforcement phase that eventually weakened the bond of reinforcing particles with the matrix [10-26]. Therefore, it can be concluded that centrifugal casting is inexpensive and feasible on an industrial scale and can effectively produce an integrated composite.

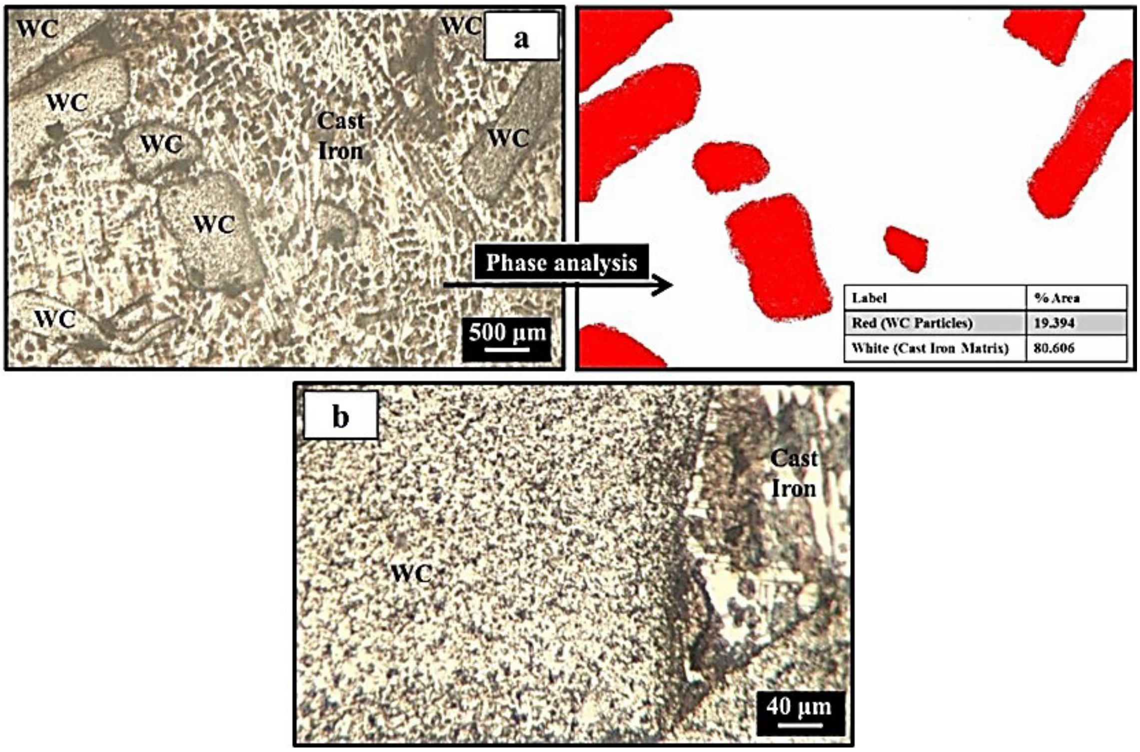

Fig. 4. (a) OM image of the microstructure of the produced cast iron/WC SMMC and image analysis results and (b) interfacial bonding at WC particle and cast iron matrix interface.

3.2. Evaluation of mechanical properties of cast samples

The surface hardness of rollers, especially those used in rolling lines, is a significant and persistent challenge faced by roller manufacturers. The higher surface hardness of rollers both increases the strength of the rollers against external forces and promotes their wear resistance. Surface local melting and surface alloying processes using high power density energy sources such as lasers and electron beams are among the most widely used methods commonly applied to improve the surface hardness of cast iron. However, the high equipment cost of these methods has limited their application on an industrial scale, leading researchers to be on a constant search for more practical and cost-effective methods [23-27].In the present study, the hardness of the reinforced sample was measured from the surface to the core using a hardness test under a load of 500 g and a dwell time of 10 s to investigate the effects of composite materials on surface hardness. Fig. 6 displays the hardness profile of the centrifugal casted SMMC sample along the radial direction. As shown, the maximum hardness occurred at the surface layer and decreased from 3 mm under the barrel surface (thickness of the composite layer).

Fig. 6 shows that the hardness value at the composite surface layer was about 1400-1800 HV (5.0), which was approximately three times greater than that of the interior zone (~ 500-700 HV (5.0)). It can be suggested that the high hardness of the composite surface layer was related to the synergistic effect of hard WC particles (the main reason), iron carbide network, and relatively hard pearlite matrix. In contrast, the acceptable hardness of the interior zone was only due to the pearlite matrix and an efficient strengthening carbide network (note the schematic microstructures assigned to each region in Fig. 6). It is worth mentioning that the variability in the hardness value obtained in each area can be owing to the collision site of the indenter. Given these results, it can be proposed that, compared to the other mentioned methods, centrifugal casting can be considered a cost-effective, alternative, and simple method that can produce rollers with a relatively thick surface layer with high hardness.

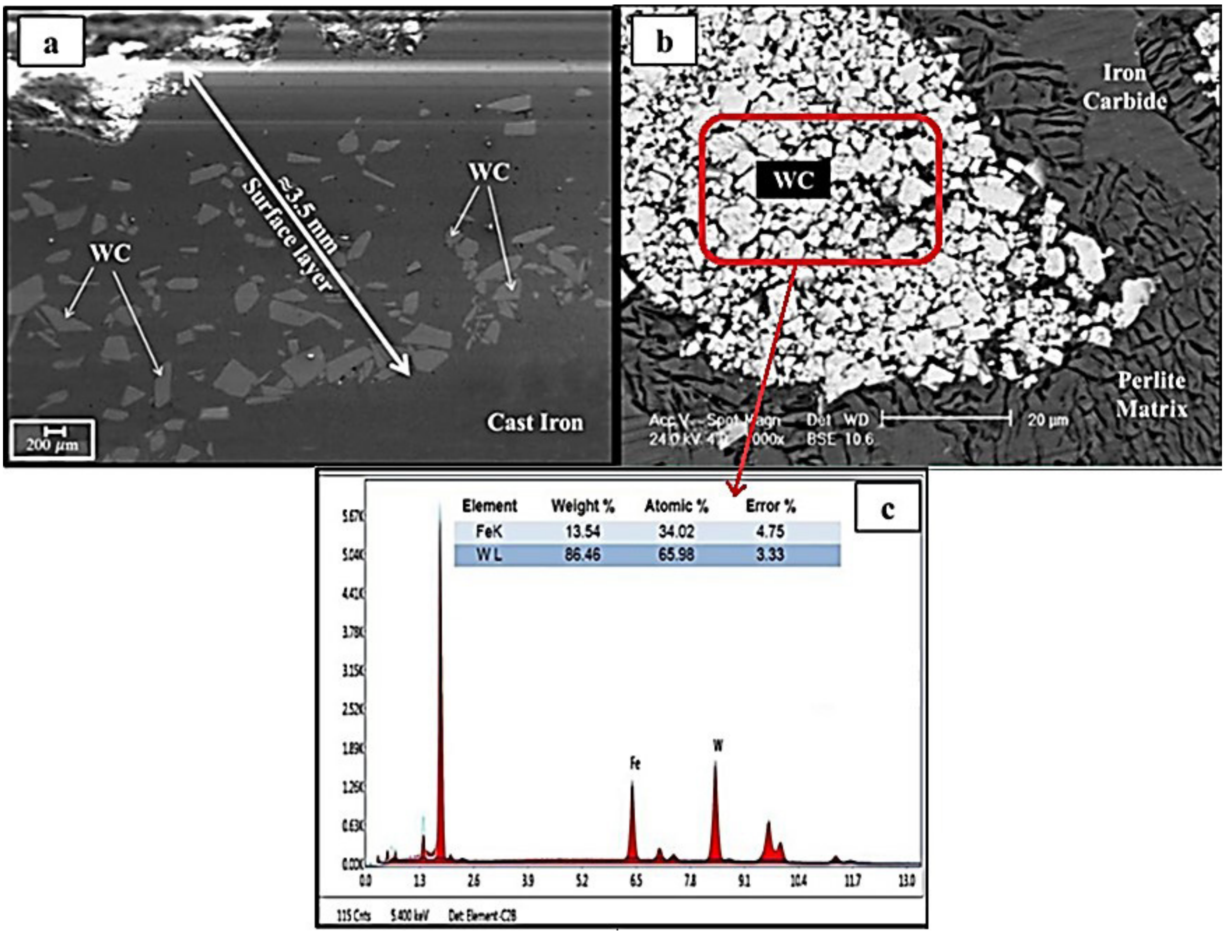

Fig. 5. (A) SEM Image of the Microstructure of Composite Surface Layer, (B) the Magnified SEM Image of a Single WC Particle, and (C) the EDX Analysis of WC Particle.

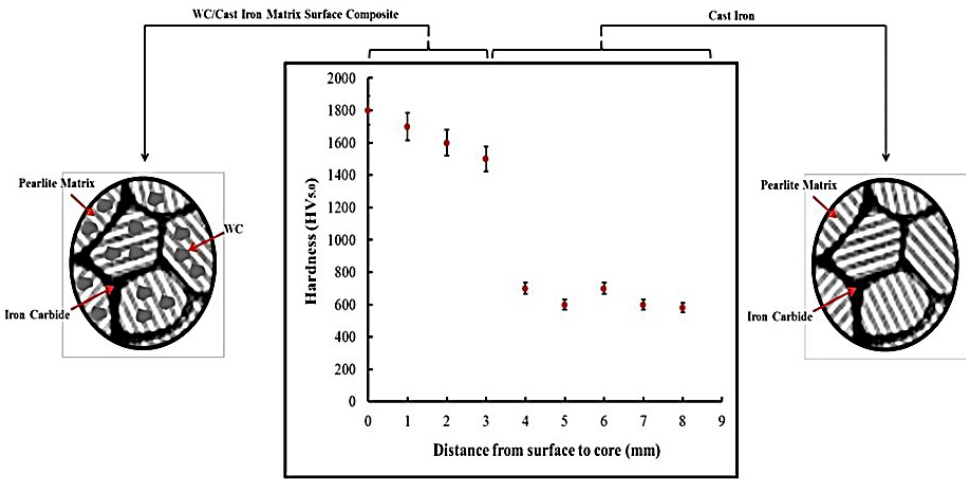

Fig. 6. The Hardness Profile of Centrifugal Casted SMMC Sample Along the Radial Direction (From Surface to Core).

The wear behavior of rollers at high temperatures is decisive for their performance and service life. Wear is a highly complex phenomenon tightly correlated to other interactions at the interface of two sliding parts and is affected by many factors, such as material characteristics, the applied wear load, and wear temperature [26]. Therefore, the wear behavior of cast samples was comprehensively investigated under normal loads of 100, 150, and 200 N at different temperatures (25 °C and 450 °C) using a ball-on-disc type wear test with an alumina ball. Moreover, in all wear tests, the sliding speed and distance were 0.2 m/s and 1000 m, respectively.

As an acceptable measurement criterion, Fig. 7 shows the weight loss of the reinforced and unreinforced cast samples as a function of wear load and temperature after a sliding distance of 1000 m. The figure indicates that in all wear conditions, the weight loss of WC-reinforced-cast iron SMMC was significantly less than that of unreinforced cast iron. This difference could be related to several factors: At 450 °C and under a load of 200 N, the weight loss of the reinforced sample decreased by about 41% compared to the unreinforced sample, indicating a significant improvement in wear behavior. Therefore, it can be concluded that, in addition to ambient temperature, the positive effects of the composite surface layer were also acceptable and effective at high temperatures and wear loads. Generally, the wear behavior of materials depends on many parameters, among which surface characteristics, such as microstructure, texture, and hardness, play the most important role [26-27]. Different equations have been proposed based on influential variables in terms of hardness effects on the wear behavior of materials. Below is one of the most common of these variables:

$$Q = \frac{KWV}{H}\left(\frac{Volume}{t}\right) \quad (2)$$

where Q is the wear rate, W, V, and H are the applied wear load, the sliding speed, and material hardness, respectively, while K is the equation constant [26].

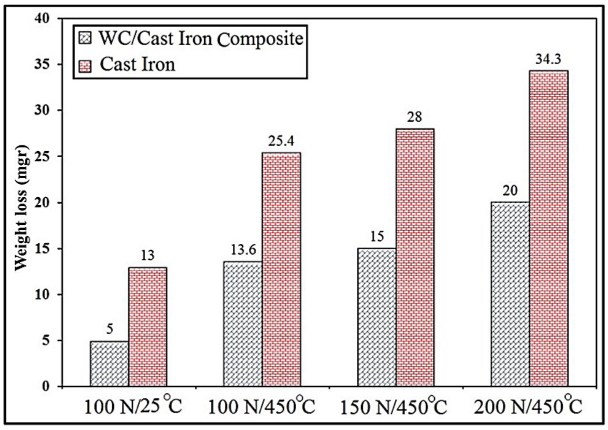

Fig. 7. The Weight Loss of Centrifugal Casted Samples Under Different Wear Conditions After Wear Distance of 1000 M.

Eq. (2) indicates that the hardness of the material is inversely related to its wear rate. The improved wear behavior of the reinforced sample compared to the unreinforced could be related to the increased hardness of its surface layer, potentially due to the presence of hard WC reinforcing particles and, consequently, the formation of SMMC. Indeed, the significant hardness of WC particles and their strong interfacial bonding with the cast iron matrix resulted in their acting as a physical barrier against the applied frictional force by the alumina ball. Moreover, by decreasing the contact area between balls and the softer cast iron matrix, the WC particles remarkably prevented the direct sliding on each other, significantly reducing the wear rate of reinforced samples. Research indicates that the amount of reinforcing particles and their distribution into the matrix can profoundly influence the wear behavior of composite samples. In this regard, it was suggested that when the amount of reinforcing particles is much less than that of the matrix (incorporating only a very low volume fraction of reinforcing particles in the composite matrix), matrix characteristics, including its microstructure and hardness, could determine the wear behavior of the composite sample, whereas, with increasing the volume fraction of reinforcing particles, the role of these particles in improving the wear behavior of the composite sample is dramatically enhanced [26-28]. However, an excess number of reinforcing particles, more than a critical value, is completely unsuitable since it leads to agglomeration of these particles and their non-uniform distribution and forms solid interfacial bonding between them. Furthermore, the matrix requires the presence of a sufficient amount of the matrix as the environment surrounding the particles [11 -26]. The results revealed the decisive role of WC particles in improving the wear behavior of composite samples. This finding can be conclusive evidence for the correct choice of the amount of these particles and casting parameters during the production process of SMMCs samples, eventually leading to their uniform distribution in the matrix and strong interfacial bonding at the WC/cast iron interface and promoting wear resistance. Also, the formation of a pearlite phase with a continuous iron carbide network as a matrix contributed to the proper effectiveness of WC particles in improving wear behavior, as research shows that such a structure has high wear resistance. Moreover, it was found that, with increasing sliding distance, the WC particles not damaged by wear were placed in a higher position than the sample surface and had the most contact area with the abrasive ball. One possible explanation is that the wear had occurred at the lowest rate for high sliding distance. According to Fig. 7, as expected, the wear rate of all samples, i.e., reinforced and unreinforced, increased by increasing the applied load and temperature of wear tests. However, it was observed that the SMMCs samples exhibited much better performance compared to unreinforced samples at high temperatures and applied loads. The present study recorded the friction coefficient as a sliding distance function for all wear conditions (see Fig. 8). In summary, the average friction coefficient and the specific wear rate of all samples at different wear conditions were determined (Table 2). As shown in Fig. 8, the friction coefficient initially increased and reached an almost stable value with increasing sliding distance. At all wear conditions, the friction coefficient of SMMCs was greater than that of unreinforced samples, relating to the high surface hardness of SMMCs. Indeed, the higher the surface hardness, the more horizontal load is needed to slide the ball on the disk, which increases the friction coefficient between two sliding counterparts. Moreover, the results indicated that, as expected, the friction coefficient of samples decreased with increasing temperature and, at a constant temperature, increased with increasing applied load. Several factors can be involved in increasing the friction coefficient with increasing applied load: First, plastic deformation that leads to work hardening of the surface, and second, increased conflict of sliding surfaces in contact with each other, which enhances the frictional force for sliding.

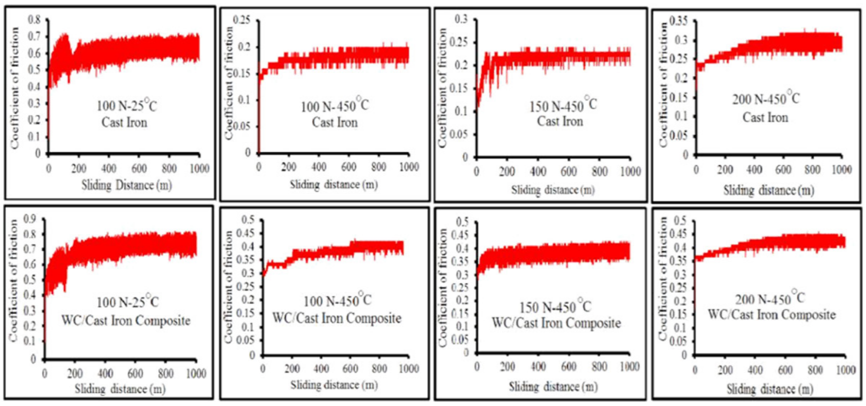

Fig. 8. The Friction Coefficient Changes of Cast Samples Under All Wear Conditions as a Function of Sliding Distance.

Table. 2. The Average Friction Coefficient and Specific Wear Rate of the Cast Samples Under All Wear Conditions.

	Coefficient of Friction		Specific Wear Rate $\left(\left(\frac{mm^3}{N.m}\right) \times \mathbf{10^{-6}}\right)$	
Force/Temperature	Cast Iron	WC/Cast Iron Composite	Cast Iron	WC/Cast Iron Composite
100 N/25 °C	0.6	0.7	17.7	6.81
100 N/450 °C	0.18	0.378	34.6	18.5
150 N/450 °C	0.21	0.38	25.4	13.6
200 N/450 °C	0.28	0.41	23.3	13.6

Fig. 9 demonstrates the OM, SEM images, and EDX spectra of the wear pattern of reinforced and unreinforced samples at 450 °C under the load of 100 N after a sliding distance of 1000 m. As shown, a groove-like pattern parallel to the wear direction was observed on the worn surface of two types of samples, confirming the abrasive wear mechanism. It was reported that the abrasive wear mechanism of hard phase-based composite involved the plowing and removal of the softer material (matrix phase), which was detected by grooves on the worn surface, fragmentation, and peel-off of challenging phases. However, the finding revealed that the hard WC particles were not, herein, affected by abrasive balls even after a sliding distance of 1000 m, indicating that they were well able to resist the frictional force as a physical barrier and improved the wear behavior of SMMCs. However, according to Fig. 9, EDX spectra of reinforced and unreinforced samples show that, at high temperatures, a layer of iron oxide forms on the worn surface as a solid lubricant film, which was a reason for decreasing the friction coefficient at high temperatures. However, since the formed oxide film did not sufficiently adhere to the worn surface, the repeatable sliding contact led to the fracture of the iron oxide film, and detached oxide debris increased the wear rate. It can be claimed that the fluctuations in friction coefficient during wear evaluation can be related to the contradictory behavior of oxide film, as mentioned above.

To better understand the wear behavior of WC-reinforced-SMMCs, Fig. 10 shows a schematic of the wear mechanism in this material that indicates the effective role of WC particles in improving the wear behavior of SMMCs. In sum, findings revealed that the centrifugal casting process, as a simple and operational method, can be used to produce SMMCs on an industrial scale with acceptable results. Moreover, hard WC particles, as reinforcing phase, have dramatically improved the wear behavior of cast iron as matrix phase at different wear conditions, particularly relatively high temperatures. Therefore, WC-reinforced cast iron-based SMMCs can be a good and promising candidate for manufacturers to use in rollers of rolling lines.

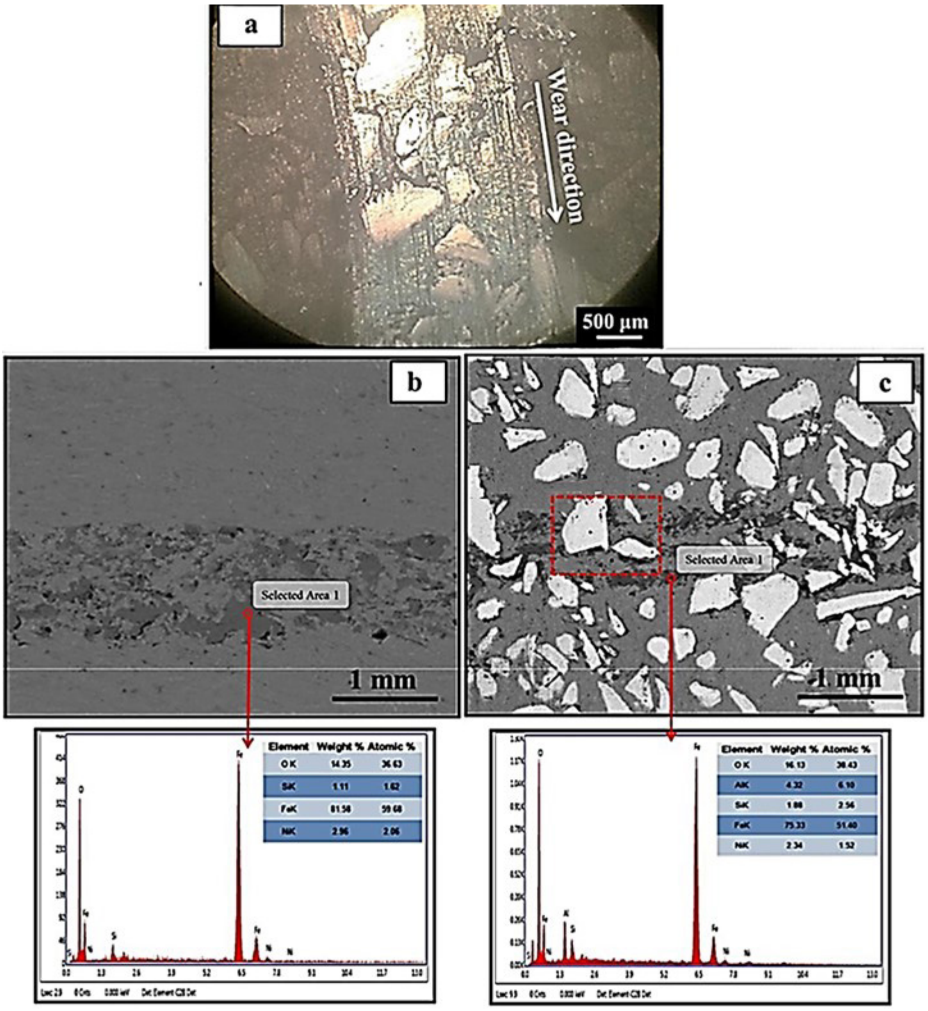

Fig. 9. The OM, SEM Images, and EDX Spectra of the Wear Path of (A and C) Unreinforced and (B and C) Reinforced Samples at 450 °C Under the Load of 100 N After a Sliding Distance of 1000 M.

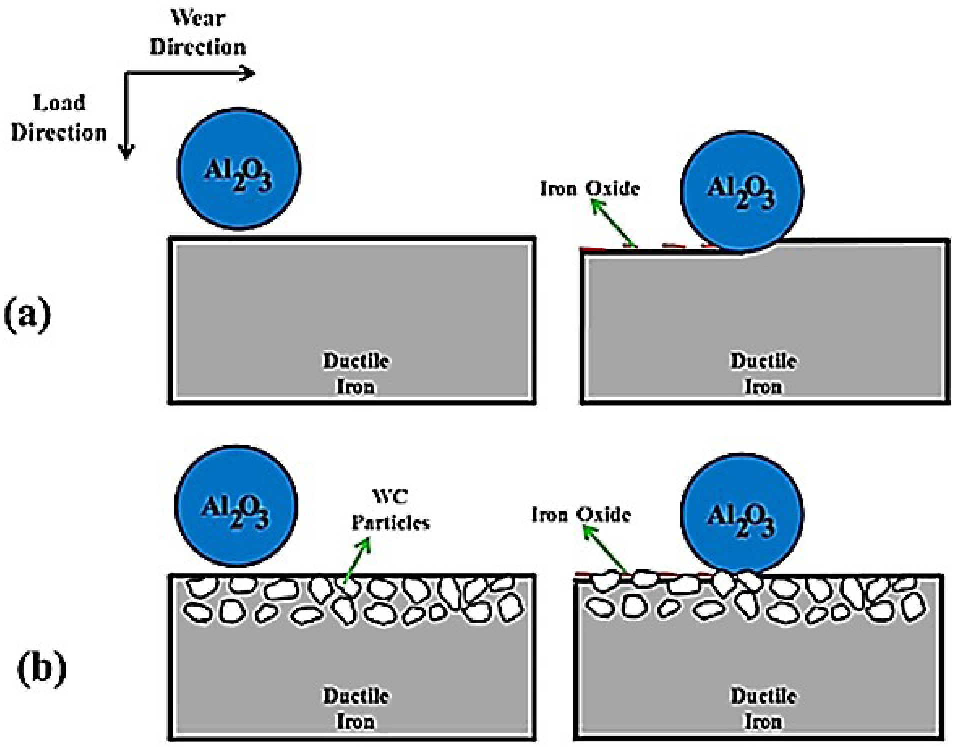

Fig. 10. A Schematic Representation of the Wear Mechanism in (A) Unreinforced and (B) Reinforced Centrifugal Casted Samples.

4. Conclusions

The microstructure and wear behavior of a WC-reinforced cast iron-based surface metal matrix composite were investigated. The composite was produced using a centrifugal casting process as a candidate for use in rolling line rollers. To do so, the wear behavior of centrifugal cast samples was evaluated at 25 °C and 450 °C under normally applied loads of 100, 150, and 200 N after a sliding distance of 1000 m.

The following conclusions were drawn:

- Results indicated that WC-reinforced cast iron-based SMMC was successfully produced using centrifugal casting. The thickness of the surface composite layer was 3 mm. As a result, the production of SMMCs with such a thick surface composite layer can be considered an advantage compared to other production methods.
- Microstructural characterization showed that the microstructure of the unreinforced sample consisted of a pearlite matrix with a continuous network of iron carbide. In contrast, the reinforced sample cast sample microstructure was divided into two distinct regions: First, the surface layer with a cast iron matrix (a pearlite matrix with a continuous network of iron carbide) and uniformly distributed WC reinforcing particles. Second, an interior zone with a common cast iron structure under rapid solidification rate (similar to the microstructure of the unreinforced sample). Moreover, it can be observed that the WC particles did not react with cast iron during the casting process and strongly bonded with the matrix phase at the WC/cast iron interface, which can be significant evidence of the success of the production method.
- The hardness value at the composite surface layer was approximately three times greater than that in the interior zone, attributable to the synergistic effect of hard WC particles, iron carbide network, and relatively hard pearlite matrix. This feature played an important role in improving the wear behavior of SMMCs.
- At different temperatures and applied loads, the weight loss of WC-reinforced-cast iron SMMC was significantly less than that of unreinforced cast iron. Indeed, besides ambient temperature, the beneficial effects of the composite surface layer were acceptable and effective at high temperatures and loads of wear. For example, at 450 °C and 200 N of load, the weight loss of the reinforced sample decreased by about 41% compared to the unreinforced sample. Various reasons were found for this superiority of WC-reinforced cast iron-based SMMC, such as the high hardness of WC particles, their strong interfacial bonding at the interface of WC-cast iron, and the favorable characteristics of the cast iron matrix.
- The results of the present study hopefully suggest that centrifugal casting can be an efficient and cost-effective method for producing WC-reinforced cast iron-based SMMCs, as a suitable material for the rollers of rolling lines.

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