Present Situation and Key Technology Analysis of Bimetallic Composite Roll Preparation Method

Xiaofang Shi, Chunli Zhu, Zhenghai Zhu and Lizhong Chang *
School of Metallurgy engineering, Anhui University of Technology, Ma’anshan, 243002, China
E-mail:clz1997@163.com

Abstract. Bimetallic composite roll has a great influence on improving roll quality and reducing roll preparing cost. In this paper, the development status of bimetallic composite roll preparation technology is analysed, and the advantages and disadvantages of various manufacturing methods of composite roll are discussed. Based on the preparation process of bimetallic composite roll, the key technologies affecting the quality of composite roll are analyzed, and a new idea of preparing high-performance composite roll based on "width adjusting mold coupling multi-electrode rotating technology" is proposed.

1. Introduction
The consumption of wear-resistant parts in metallurgy, mining and other industries is very large, and many parts fail due to wear. If these wear-resistant parts are made of high hardness materials as a whole, not only the preparation cost is increased, but also the machining difficulty of non-working surface is increased too. For this reason, bimetallic composite materials are coming. That is, the materials with high hardness, good wear resistance and high price are used in the working surface, while the non-working surface adopts relatively cheap materials with high toughness, processing performance[1].

The most typical and widely used bimetallic composite material is the roll for metallurgical industry, which is the main tool for steel rolling. The shell and core of the roll are made of different materials, which can not only meet the requirements of the rolling mill for good wear resistance and thermal fatigue resistance of the shell of the roll, but also ensure the strength and toughness of the core. More importantly, the preparing cost of the roll is greatly reduced. Taking the high speed tool steel roll as an example, if the roll is made entirely of high speed steel, the preparing cost is very high. If the bimetallic composite roll is used, that is, the low-alloy steel with low price is used for core and the high-speed tool steel is used for the shell, the preparing cost will be greatly reduced.

In order to achieve the above goals, metallurgical workers have carried out a lot of basic research and technological development and achieved good results. Unfortunately, there are various disadvantages in these achievements, which limit the wide application of bimetallic composite roll. Especially in the field of cold rolling, the roll is still made of the same material. In view of this situation, this paper mainly introduces the research status of composite roll preparation technology, and discusses the advantages and disadvantages of various technologies. Based on this, the authors analyze the key factors affecting the quality of composite roll and put forward their own views.
2. Development Status of Bimetallic Composite Roll Preparing Technology

2.1. Washing Method
In the 1930s, the washing method was invented to prepare composite roll and the preparation principle is shown in Figure 1. First, the melted liquid iron is poured into the mold through the pouring cup until it reaches the riser. After the molten iron contacted with the metal mold solidifies to a certain thickness (equivalent to the shell of the roll), the common molten steel is poured into the mold through the pouring cup and wash away the molten iron in the roll core from the upper part of the mold. Then, the fusion and diffusion between molten steel and the solidified shell metal will happen so as to form a composite roll. This method is easy to operate and the shell of roll with low segregation can be obtained due to the rapid cooling of the metal mold. However, the biggest disadvantage of this method is that a large amount of molten iron must be melted, the metal yield of casting is low, and the energy consumption is large. Moreover, when preparing high alloy composite roll, the shell material and the core material are inevitably mixed due to washing the core and the alloy loss is very large. At the same time, the purity of core is decreased and the manufacturing cost is increased.

Figure 1. Washing method

2.2. Centrifugal Casting
At present, the more popular preparing method of composite roll is centrifugal casting technology, which originated in the late 1960s, developed rapidly in the 1970s and has been used up to now[2-5]. The working principle (taking horizontal centrifugal casting as an example) is shown in Figure 2. First, the molten steel, namely, the shell material of composite roll is poured into the mold rotating along the horizontal axis and solidified under centrifugal force and rapid cooling of mold. Then, the whole mold is quickly lifted and placed vertically, followed by the pouring of molten steel as the core from the upper part until the riser is filled. The composite roll with different shell and core components is preparing.

Compared with the washing method, the centrifugal casting has the following characteristics: 1) the yield of metal is significantly increased; 2) a large number of alloy materials are saved; 3) the surface quality of roll is improved; 4) the strength of roll neck is significantly increased.

Although centrifugal casting is widely used in the preparation of composite rolls, there are many problems in the production of high alloy composite rolls, especially high speed tool steel composite rolls. The main reasons are as follows [6-7]:

1) Due to the high content of V, W, Mo and Cr in high speed steel, the density of carbides formed through the reaction of these elements and carbon is very different. When centrifugal casting is used, the density of VC precipitated in the early stage of solidification is less than that of molten steel and it
will concentrate on the surface of mold under centrifugal force which can lead to uneven distribution of structure and composition.

2) When the core of roll is made of high-strength cast steel with higher melting point, the molten cast steel will fuse with the solidified high speed steel shell during the centrifugal casting. The fusion layer with lower melting point between cast steel and high speed steel may be the end-solidification position which can easily cause casting defects and decrease the strength of the joint.

To solve the above problems, the researchers have developed electromagnetic stirring centrifugal casting technology in recent years [8-12]. It is found that the segregation of high speed steel composition roll can be reduced obviously by adding electromagnetic stirring during centrifugal casting, which provides a new idea for the further development of centrifugal casting technology.

2.3. CPC Technology
CPC Technology, Namely continuous pouring process for cladding, the structure of which is shown in Figure 3[13-19].

![Diagram](image1)

**Figure 3. CPC Technology**

The core material of composite roll is made of forged steel or cast steel, and then a concentric water cooling mold is arranged around the vertical core. The molten steel is poured into the gap between the vertically arranged core and the water-cooled mold. The shell is progressively solidified to be tightly bonded with the core and is intermittently withdrawn downward to form the composite roll [13]. In order to make the molten steel effectively fused with the core, the electromagnetic induction heating device is used to heating core and molten steel. During the bonding process, slight melting occurs on the surface of the core, which makes the core and shell realize effectively metallurgical bonding and improves the bonding strength. A fine cast structure is obtained due to the high solidification and cooling rates and there are almost no solidification defects such as shrinkage cavity and porosity. The overall performance of the composite roll by CPC technology is better than that of the common centrifugal casting high speed steel roll. CPC technology not only overcomes the segregation defect caused by centrifugal casting, but also uses strong, tough and rigid steel as the core material.

However, the equipment and process of CPC method are complex, and improper process control may lead to poor bonding between the roll core and shell. In addition, compared with electroslag remelting, the purity of molten steel as shell material is inferior (except by electroslag refining).
2.4. Electroslag Surfacing with Liquid Metal (ESS LM)

In order to improve the quality of composite roll and reduce its manufacturing cost, the electroslag surfacing with a liquid metal is developed based on the electroslag remelting technology and the metallurgist at home and abroad have done a lot of basic research too, as shown in Figure 4. A concentric water cooling mold is arranged around the vertical roll core. The slag, melted in a separate vessel, is poured into a gap between the core and mold and the voltage from the power source is supplied. The mold is not only a device, forming a deposited layer, but also the non-consumable electrode, which maintains the slag process, the heat generated in the slag pool melts the surface of core. Then, the liquid metal (Namely the shell material) is poured into the above-mentioned gap and contacts the fused surface of the core, thus forming the deposited layer. During cladding the billet is continuously withdrawn from the mold until producing the deposited layer of the preset length [20-24]. With the electroslag surfacing with a liquid metal, the production efficiency of composite roll is very high and the thickness of shell is controllable.

The first industrial electroslag surfacing equipment with a liquid metal in the world for production of composite rolls of up to 1000 mm diameter, up to 2500 mm length of the barrel and up to 20000 kg mass, was created at the Novokramatorsk Machine-Building Works. The testing of these rolls in a wide-strip mill showed that the life of rolls is 4 - 4.5 times higher than that of standard cast iron rolls used earlier. Figure 5 is the appearance of ESS LM composite billet of HSS roll [24].

However, it is a pity that up to now, this method has not been industrialized in China. Although this technology has many advantages, the author thinks that this method has the following shortcomings. 1) The molten steel has not been effectively refined. It has been confirmed that the removal of inclusions mainly occurs in the formation of droplets during ESR [25-26], and ESS LM don’t undergo the process of consumable electrode melting and droplet formation. Therefore, the removal effect of inclusions may not be as good as the traditional ESR technology. 2) There were some technical challenges. For example, the tundish needs to be heated, and the liquid metal dropping process needs to be protected to prevent air oxidation, etc.

![Figure 5. Appearance of ESS LM composite billet of HSS roll](image)

![Figure 6. Rotational electroslag remelting bimetallic method](image)

2.5. Rotational Electroslag Remelting Bimetallic Method

In order to make full use of the advantages of ESR technology, the rotational electroslag remelting bimetallic method was developed for manufacturing a composite roll, as shown in Figure 6[27].

Compared with the common electroslag remelting, this technology has the following two characteristics: (1) Pipe consumable electrode is used. Before the electroslag remelting, the roll core is placed vertically in the mold, then the pipe electrode is inserted into the gap between the core and mold. The gap is filled continuously with the molten pipe electrode to form the shell of roll. (2) The mold rotates with the core during electroslag remelting. Rotation can ensure that the temperature of the slag pool is uniform, so that the shell material is evenly covered on the core.
By rotational electroslag remelting bimetallic method, the shell material of roll can be refined and the large inclusions can be removed effectively. At the same time, the rotation of mold ensures the uniformity of shell thickness. However, this method has the following disadvantages: (1) because the pipe electrode is placed between the core and the mold, the gap between the core and the mold cannot be too small for safety, so the adjustment of the thickness of the shell is limited. (2) The temperature of slag pool is very high, and the speed of ESR is very slow, which may lead to a large amount of dissolution of core material, mixing the shell material with the core material, and finally changing the composition of shell material. Therefore, how to coordinate the temperature of slag pool with the melting speed of core is a difficulty.

Based on the above technologies, the author thinks that the preparation of bimetal composite roll based on electroslag remelting technology is the most promising. The main reasons are: (1) The purity of shell material can be greatly improved after remelting; 2) Due to the rapid cooling of water-cooled mold, a fine solidification structure is obtained. 3) The surface quality of roll is very good too. However, in order to further improve the quality of composite roll, a lot of basic research and technical development are needed.

3. Key Technologies Analysis and Solution of Bimetal Composite Roll Based on ESR

From the development process of bimetal composite roll, the key technologies are as follows:

(1) Because the roll works under the conditions of high temperature, high pressure and periodic impact, it is required that the roll has high surface hardness, wear resistance and heat resistance. For the composite roll, the life of roll determined by the quality of shell material. Therefore, it is necessary to ensure the purity and good solidification quality of the shell material.

(2) The thickness of the shell is controllable. According to the diameter and service conditions of the roll, the thickness of shell of the composite roll must be adjustable to meet different demand.

(3) The shell material can be evenly cladded on the core, that is, the thickness of shell is consistent along the longitudinal and radial direction which can not only avoid the defects for the ultrasonic testing, but also reduce the probability of roll failure before its service deadline.

(4) Effective fusion of shell and core material. The thickness of the transition layer at the fusion position should be appropriate, which not only ensures the effective fusion between the shell and the core, but also cannot make the core melt excessively, so as to change the composition of the shell material.

Among the above four problems, the author thinks that how to bond the shell with the core effectively is the most important problem. There are two ways for metals to bond with each other: liquid-solid bonding and solid-solid bonding. Obviously, the preparation of bimetal composite roll belongs to liquid-solid bonding.

The interface bonding modes of bimetal composite materials prepared by liquid-solid method include mechanical adhesion, diffusion and fusion.

The mechanical adhesion refers to no diffusion between two metals during the bonding process. In spite of the contact between the core and the liquid metal (shell material), there is no mutual diffusion between the two metals due to the lack of infiltration and the rapid solidification of the liquid metal, and only mechanical adhesion exists between core and the shell. Obviously, it is difficult to meet the requirements only by mechanical attachment and the bonding layer is likely to be torn under rolling force.

Diffusion and fusion is based on the micro melting on the surface of core. The superheated liquid metal takes the surface of the core as the base and begins to solidify, forming an interface region differing from the normal solidification structure of the shell metal [28-29]. The effective metallurgical bonding of the shell and the core can be realized through the micro melting of the core surface, which can meet the rolling requirements.

However, the biggest difficulty lies in how to make the surface of the core micro melting and determine the thickness of micro melting layer. Too much melting on the surface of core causes it to mix with the shell material, and even changes the composition of the shell material. If the melting is too little, the core and shell may not be well fused.
Based on the above problems, the author proposes the following solution, that is, the mold width adjusting and multi-electrode rotation technology, as shown in Figure 7.

The key technologies are as follows:

1) Technology of mold width adjustment, the purpose of which is to adjust the melting thickness on the surface of core. As mentioned above, the key for the effective bonding of the shell and core is to have a proper melting thickness on the surface of core. In the traditional electroslag remelting process, the temperature of the slag pool and the melting speed of the consumable electrode do not change much while the mold diameter remains unchanged. As shown in Figure 7, in the case of electroslag remelting with ingot drawing, the liquid steel level should remain unchanged for stabilizing the remelting process, that is, the speed of ingot drawing should match the melting speed of consumable electrode. When the diameter of slag pool is kept constant, the melting speed of consumable electrode and the speed of ingot drawing, namely the speed of core passing through slag pool are also kept constant. If the diameter of the slag pool is too large, the melting speed of the consumable electrode will be accelerated, and the time for the core to stay in the slag pool will be shorter which may cause the melting depth of the surface of core to be too shallow. If the diameter of the slag pool is too small, the melting speed of the consumable electrode is too slow, and the time for the core to stay in the slag pool will be longer, which may lead to excessive melting of the core. When the diameter of mold is adjustable (namely the diameter of slag pool), the melting speed of consumable electrode and the speed of ingot drawing is adjustable. Therefore, the residence time of core in the slag pool also changes and the melting depth of the surface of core can be adjusted. As the diameter of mold is widened or narrowed, the melting depth of the surface of core becomes deeper or shallower to meet the requirements of the process.

2) Consumable electrode rotation technology, the purpose of which is to make the shell material clad the core evenly. Either way, the temperature of liquid metal around the core cannot be completely consistent, and electroslag remelting is no exception, which lead to the different thickness of shell, and ultimately affect the service life of the composite roll. As shown in Figure 7, the uneven temperature of slag pool will inevitably lead to the different depth of melting layer on the surface of core. Therefore, it is assumed that during the electroslag remelting process, the consumable electrode will rotate around the center line of the slag pool to stir the slag pool, which will promote the temperature uniformity of the slag pool. On this point, the author has done a lot of pre-tests to verify that the temperature of the slag pool becomes more uniform through the relative movement between the slag pool and the consumable electrode [30].

![Diagram](image_url)

1- Consumable electrode; 2-Core; 3-Slag pool; 4-Shell; 5- Width adjustment mold

**Figure 7.** Width adjusting mold and multi electrode rotation technology

At present, the numerical calculation and the hot experiment is being carried out for the above ideas and further research results will be published later.
4. Conclusions
The bimetallic composite roll has been paid more and more attention by roll industry because of its superior performance and good economy. However, due to various reasons such as technology and management, the roll is still made of the same material in the field of cold rolling. With the rapid development of electroslag technology in recent years, a variety of new electroslag technologies emerge one after another. The electroslag rapid remelting furnace and conductive mold technologies have been industrialized, and a lot of basic research has been done on electrode rotation technology. However, how to further apply ESR technology to the manufacturing of high quality composite roll needs still great efforts.

5. Acknowledgements
The authors would like to express their gratitude to national natural science foundation of China for financial support(Grant No. 51774003).

6. References
[1] Li X Q, Song Y P. Present situation and prospect of foundry techniques for bimetallic compound rolls, MATERIALS RESEARCH AND APPLICATION, 2010, 4(3): 164-168.
[2] Fu H G, X Q. Manufacturing Technology for Bimetallic Roller by Centrifugal Casting, Special-cast and Non-ferrous Alloys, 1997, 17(3): 51-54.
[3] Nastac, Laurentiu. Numerical Modeling of Carbide Redistribution during Centrifugal Casting of HSS Shell Rolls, ISIJ International, 2014, 54 (6): 1294-1303.
[4] Kenji Ichino,Yoshihiro Kataoka,Tomoya Koseki. Development of Centrifugal Cast Roll with High Wear Resistance for Finishing Stands of Hot Strip Mill, Kawasaki Steel Technical Report, 1997, 37 (10): 13-18.
[5] Okabayashi Akitoshi, Morikawa Hajime, Tsujiimoto Yutaka. Development and characteristics of high speed steel roll by centrifugal casting, SEAISI Quarterly (South East Asia Iron and Steel Institute), 1997, 26(4): 30-40.
[6] Luan Y K,Song N N, Bai Y L et al. A segregative MC carbide in centrifugal casting high speed steel roll, 2010 International Conference on Advances in Materials and Manufacturing Processes, China, 2010: 154-155.
[7] Fu H G, Xiao Q, Xing J D. A study of segregation mechanism in centrifugal cast high speed steel rolls, Materials Science and Engineering A, 2008, 479(1-2): 253-260.
[8] Fu H G, Mi S L, Xing J D et al. Study on Decreasing Segregat ion of Centrifugal Cast High Speed Steel Roll, FOUNDRY, 2005, 54(4): 386-390.
[9] Ge Yunlong, Yang Yuansheng, Jiao Yuning et al. Electromagnetic centrifugal casting process. Acta Metallurgica Sinica Series B, Process Metallurgy & Miscellaneous, 1993, 6B (5):349-350.
[10] Zhang T, Wang Q, Song X, Fu H.Effect of electromagnetic centrifugal casting on solidification microstructure of cast high speed steel roll, Materialwissenschaft und Werkstofftechnik, 2011, 42(6):557-561.
[11] Fu Han-Guang, Xing Jian-Dong. A fundamental research of electromagnetic centrifugal cast High Speed Steel (HSS) roll, Steel Research International, 2007, 78(3): 266-272.
[12] Zhang X D, Liu W, Li Q L et al. Effect of magnetic field on solidification structure of a centrifugal cast high speed steel roll, Materials Science and Technology, 2010, 26(10):1177-1183.
[13] Mitsuo HASHIMOTO, Taku TANAKA, Tsuyoshi INOUE et al. Development of Cold Rolling Mill Rolls of High Speed Steel Type by Using Continuous Pouring Process for Cladding, ISIJ International, 2002, 42 (9): 982-989.
[14] Tanaka Taku, Koie Takayuki, Ayagaki Masatoshi et al. High speed steel type cold rolling mill roll by continuous pouring process for cladding, Nippon Steel Technical Report, 2002, 86: 80-85.
[15] Kerr. E, Webber. R, McCaw. D. Roll performance-technical overview and future outlook, Ironmaking and Steelmaking, 2004, 31 (4): 295-299.
[16] Hashimoto Mitsuo, Sasaki Mantaro, Ishii Yoshio. Rebirth of CPC roll with HSS material for hot strip finishing mill, *AISTech 2011 Iron and Steel Technology Conference*, Indianapolis, United states, 2011.05.

[17] Lee Gene E, Lopez, Felix. Fujico's CPC/HSS roll performance at CMC's Arizona micro-mill and in North America, *Iron and Steel Technology*, 2013, 10 (8): 121-126.

[18] Wan H. FEM simulation of continuous casting temperature field for high-speed steel rollers by CPC method and optimum design of parameters [D], Wuhan University of Technology, Wuhan, 2008.

[19] Takeuchi E, Zene M. Novel continuous casting process for clad steel slabs with level de
magnetic field, *Ironmaking and steelmaking*, 1997, 24(3): 257-163.

[20] Dong Y W, Zheng L C, Jiang Z H. Mathematical modelling of producing hollow ingot by electroslag casting with liquid metal, *Ironmaking and Steelmaking*, 2013, 40 (2): 153-158.

[21] Rao L, Wang S J, Zhao J H et al. Experimental and Simulation Studies on Fabricating GCr15/40Cr Bimetallic Compound Rollers Using Electroslag Surfacing with Liquid Metal Method, *Journal of Iron and Steel Research(International)*, 2014, 21(9): 869-877.

[22] Medovar Lev, Stovpchenko Ganna, Fedorovski Borys et al. ESR technologies utilizing liquid metal: process, equipment and products, *Proceedings of the fifth baosteel academic annual conference*, 2013.

[23] Jiang Z H, Cao Y L, Dong Y W et al. Numerical Simulation of the Electroslag Casting With Liquid Metal for Producing Composite Roll, *Steel research international*, 2016, 87 (6): 699-711.

[24] L.B. MEDOVAR, A.K. TSYKULENKO, V.Ya. SAENKO et al. New Electroslag Technologies, *Medovar Memorial Symposium*, 2001: 49-60.

[25] Li Z B. Electroslag Metallurgy Theory and Practice, Beijing: Metallurgical Industry Press, 2010.

[26] Li Z B. Development of electroslag metallurgy and casting in China, *China foundry*, 2004, 1(1): 7-16.

[27] Masaki SHIMIZU, Osamu SHITAMURA, Shusuke MATSUO. Development of High Performance New Composite Roll, *ISIJ International*, 1992, 322(11): 1244-1249.

[28] Liu Y H, Liu H F, Yu S R et al. Study on Interface of High Speed Steel/Structural Steel Bimetal Composite, *Special-cast and Non-ferrous Alloys*, 2001(2): 17-19.

[29] Li W M, Jiang Z H, Dong Y W et al. Present situation of theoretical research on interface of compound roll, *Journal of Materials and Metallurgy*, 2011, 10(S1): 77-80.

[30] Shi X F, Chang L Z, Wang J J. Effect of mold rotation on the bifilar electroslag remelting process, *International Journal of Minerals, Metallurgy and Materials*, 2015, 22(10): 1033-1042.