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New trends and advances in bi-metal casting technologies

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The technology of bi-metal casting is considered one of the promising technologies in the field of casting industry. The main applications of bi-metal casting are dynamic loads and intensive abrasive wear. Understanding of the process and its dynamics are the main tool for successful bi-metal casting products. This review aims to focus on the past and present techniques of bi-metal casting in order to facilitate its production processing and improve its products performances. The advantages and limitations of liquid-solid and liquid-liquid bi-metal casting configurations are shown. New trends in bi-metal casting are classified into two categories; the first one depends on the production processing, such as continuous casting and electroslag heating processes while the second one depends on product applications, like corrosion resist, heat resist and bearing layered castings. In this review, the significance of factors affects the process of bi-metal casting to achieve high quality products is presented. Bi-metal casting interface is considered one of the most important factors that achieve a stronger bond between the pair of metals. The current review will handle the present and future status of the bi-metal casting, along with their applications in the manufacturing of certain metal products. The technical and economic environment, which is prompting the improvement of this technology will be clarified. Although new trends and developments of bi-metal casting reported, there are still many future challenges for developing bi-metal casting industry in order to increase bi-metal quality, its performance and decrease its production cost.

1. Introduction

Recently, there have been observable and developing interests for castings with unique properties such as wear and corrosion resistances. The traditional casting processes often produced entirely from expensive metals, such as Ni, Co, Ti, and/or other elements (Wróbel, 2014). There are many methods used for fabrication metallic coatings on materials for specific properties. Mold cavity preparation is casting technology in which the element of the working surface layer of the casting placed in a form immediately before pouring the other molten metal. This casting technology method considered the most economical way to enrichment the surface of castings that allows the production of layer elements directly in the process of casting. Therefore, this technology can provide highly competition for the other commonly used welding technologies and thermal spraying, for its economic advantages and low cracks formation, which arises because of making layer by welding method.

Layer casting technology was taken from the pertinent mining industry method of manufacture of different composite layers of surface based on granularity inserts from Fe-Cr-C alloy and placed in mold just before pouring molten metal into mold cavity. Obtained surface layers by this way working have a high hardness and metal-mineral wear resistance (Heijkoop and Sare, 1989; Gawronski et al., 2004; Baron et al., 2007; Klimpel, 2000; Brytan et al., 2010; Bonek and Dobrzański, 2006; Lisiecki and Klimpel, 2008; Dobrzanski et al., 2009; Labisz et al., 2010; Cholewa et al., 2010). Bi-metallic material is considered an advanced functional material in many fields because of its unique physical and mechanical properties that can be fabricated by bonding both similar and dissimilar materials.

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The bond of pair of metals is mainly depended on the wettability, reactivity, melting temperature, thermal conductivity and thermal expansion of both metals (Manesh and Taheri, 2003; Paramsothy et al., 2008; Abbasi et al., 2001; Kurt and Calik, 2009; Simsir et al., 2009; Xiong et al., 2011). There are several fabrication methods of bi-metal, such as casting, diffusion bonding, rolling, extrusion, cladding and powder metallurgy technologies (Yilmaz and Celik, 2003; Kurt et al., 2007; Manesh and Taheri, 2005; Kazanowski et al., 2004; Kacar and Acarer, 2004; Berski et al., 2006; Krishna et al., 2005). For the aim of producing aluminum-clad materials, special casting technologies developed over the last years. Haga and Takahashi (2004) investigated the applications of the twin roll casting process to produce clad strips at high casting speeds. However, using a bi-metal composite casting offers some benefits, because of a cohesive compound formed between the metals due to metal melting and accelerated diffusion at the interface resulting in a relatively higher bonding strength. Furthermore, clad strips can be fabricated directly from the molten base materials within a single process combining casting and joining (Nerl et al., 2014).

Numerous industries comprise impact-crushing processes of the raw material. Most common materials used for casting crusher hammers are manganese steel, chromium white iron and ceramics. Manganese steel that contain about 1.2%C and 12%Mn with its austenitic structure was invented by Sir Robert Hadfield in 1882 (El-Fawkhry et al., 2014). Some of these materials like ceramics show extreme abrasion resistance but low toughness which is not suitable for applications that involve crushing by impact (Leivo et al., 1997; Zic et al., 2009). Chromium white iron is cast materials contain high chromium content (1-35%), and carbon content between 2 and 4%. The hardness of the chromium white irons is usually higher than 60 HRc hardened by the formation of hard alloy rich M_7C_3 chromium carbides that has hardness up to 2000 HV.

Limits of mechanical properties by using mono-metallic alloys have been reached. It was found that the increasing wear resistances in certain alloys to higher values decrease the impact toughness for the same alloys. Moreover, wear becomes a significant cost factor due to repurchasing, changing wear parts and shutdown times. The manufacture of high quality bi-metallic elements becomes mandatory as they can withstand high impact loads and at the same time have abrasion resistance of highly alloys (Zic et al., 2009).

The objectives of the current work are to review different investigations carried out in the important stages of bi-metal casting process technologies and highlights its applications and advantages/ limitations. The work initially deals with different methods and recent developments in the bi-metal casting processes, followed by different techniques developed for making low cost and higher quality bi-metal casting from different alloys.

2. Types of bi-metal casting

The production technology for bimetals casting is largely determined by the combination of metals. Existing methods are generally classified in two terms: liquid + liquid and solid + liquid.

2.1. Liquid-solid configuration

In Liquid-solid manufacturing method, granular or monolithic insert (the element that enriches the surface) is directly placed in the mold just before the molten metal pouring (Fig. 1). Cholewa et al. (2010) investigated technology of bimetallic layer casting in configuration: working part (layer) from ferritic and/or austenitic stainless steel and bearing part from grey cast iron. A surface layer of 2 or 5mm thickness steel is put directly before pouring gray cast iron into mold cavity. Considerably the best results are achieved by using 5mm plate thickness. The using of thinner plates of about 2mm thickness causes their deformation in time of pouring that disqualifies this layer casting for industrial applications (Cholewa et al., 2010).

The liquid-solid bi-metal manufacturing of heat-resisting castings can mainly use for lining the quenching car of coke production. Liquid–solid bi-casting technology has been used to fabricate high chromium cast iron and medium carbon steel bimetal for mineral processing (Xiong et al., 2011). In this study, the results show that interfacial microstructure significantly affected by the volume ratios of liquid to solid. In general, an economic limitation of liquid-solid bi-metal casting method is the mandatory need to preheat the steel plate (monolithic insert) placed in the mold. This process of preheating of the plate inserts will decrease the yield of overall production processing.

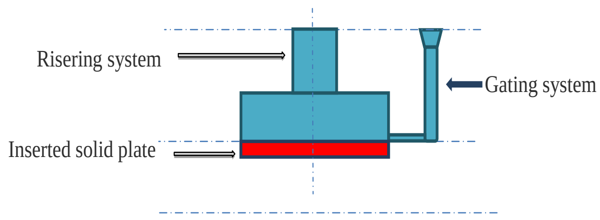

Fig. 1: Schematic illustration of liquid-solid manufacturing method

2.2. Liquid-liquid configuration

The liquid- liquid configuration bi-metal casting is a technology in which two independent gating systems are used for two-stage filling of the mold cavity (Fig. 2). The patented technology in literature (Zic et al., 2009), provides risk free operation with highly wear chromium cast iron of hammers and combined with highly impact resistant steel. This technology allows usage of hammers simultaneously combining abrasion resistance of chromium white iron with hardness up to 64 HRc and alloyed tempered steel with toughness of 28 – 32 HRc.

Bimetallic hammers are designed to extend the life of hammer application, resulting in reduced overall costs, longer mean time between failures and generally reduced overall downtime.

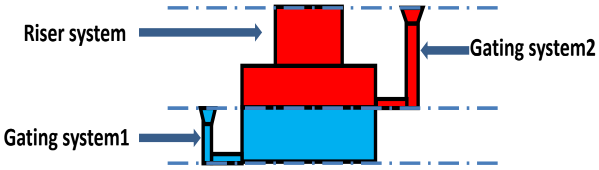

Fig. 2: Schematic illustration of liquid-liquid manufacturing method

Two different molten metals are poured into two gating design mold. A significant improvement in life span of spear parts which are subjected to both high dynamical stresses and high abrasive wear at the same time can be achieved. Nowadays, special category of rolls are commonly manufactured via bi-metal liquid-liquid method (obtained through pouring and casting of two types of alloys), with a very hard surface area, high resistance to wear and the core high resistance to bending strains. In this way, rolls with working surface hardness of 100 HSh can be achieved, thus being relatively higher resistant to wear than the rolls manufactured using one alloy. Bi-metal casting rolls from various qualities of cast iron are very important in the manufacturing of the rolls destined for various rolling-mill stands. All these particularities imprint a specific macro and microstructure to each roll (Kiss and Maksay, 2010; Spuzic et al., 1994; Corbett, 1990).

A promising approach is the continuous casting of plane or round bi-metallic blanks for subsequent plastic deformation (Hashimoto et al., 1991; Ooshima et al., 1990; Peterson and Winer, 1980; Zum Gahr, 1987; Bykov, 2011). The sequential casting of two different liquid metals ensures stronger bonding of the layers than in the previous liquid –solid case and also considerably increases the productivity, reduces the cost of the final products. Centrifugal casting processes are used to fabricate bi-metallic blanks with subsequent hot and cold plastic deformation in pipe and rod manufacturing. Casting of molten metal together with slag in a rotating mold led to the metal for the external layer is first introduced and it followed by the slag. After solidification of the first metal, with its slag coating, the second metal is poured, and the slag rises to its surface resulted in washing and mixing of the metals, a sufficiently strong bond is formed (Bykov, 2011).

3. New trends in bi-metal casting

The development in casting technologies will not stop improving. New technologies for the manufacturing and use of bi-metal casting are developed over the years. However, the new trends in the bi-metal casting processes which begin to be implemented should be more revolutionary than those discussed above so as to be competitive with the conventional casting technologies. The challenges for the developing bi-metal casting must focus on the reduction of cost and ease of production as well as improve the interface bond of the pair of metals. The following points are summary for further innovative trends in the bimetal casting.

3.1. Continuous casting

The developed continuous casting process (Nerl et al., 2014; Marukovich et al., 2006; Nerl et al., 2012) is based on casting liquid pure aluminum into a movable solid or semi-solid AlSn6Cu substrate strip. The liquid and substrate alloy passes through a ceramic inlet and solidifies in the first stage of the mold system forming on and on moving strip of 12 mm thickness. After solidification, the substrate advances in the composite casting region where pure aluminum is supplied from a vertical opening. After the liquid aluminum comes into contact with the substrate material, the metallurgical compound is formed. The composite strip is withdrawn and passes through the second cooling stage of the mold system. The mold system consists of a divided graphite mold, cooled by water-cooled copper plates, and a composite casting unit. The casting unit is made of cast iron and can be heated by electrical heating cartridges. It was found that the quality of the compound and the stability of the bi-metal casting process are mainly dependent on the thickness ratio of the bilayer strips and the withdrawal regime.

3.2. Electro slag heating

In the technology of surfacing under a layer of hot slag (Bykov, 2011; Marukovich et al., 2006; Nerl et al., 2012), the bimetal blank is produced by electro slag heating of the slag of the basic blank by non-consumable electrodes, followed by the solidification of the coating layer during electro-slag heating. The basic plate is introduced on a trolley with a hearth. Then non-consumable graphitized electrode plates are placed in the electrode holders under the plate (Bykov, 2011).

Another similar technology is electroslag surfacing by liquid metal in particular, surfacing of rollers (Bykov, 2011; Marukovich et al., 2006; Nerl et al., 2012; Medovar et al., 1996). Slag melted in a separate chamber is let in the gap between the roller surface and the mold wall. Here, the mold shapes the molten layer and also serves as a non-consumable electrode maintaining the electro-slag process (Medovar et al., 1996).

3.3. Corrosion and heat resisting layered castings

In this technology, the fabricated bi-metallic layered castings can work in conditions that require working surface layer of element with a high heat resistance and/or corrosion resistance as in industrial water production and lining of quenching car used in coke production (Wróbel, 2011).

The casting parameters that affect the interface bond between stainless steel and graphitic cast iron have been investigated. Gray cast iron and stainless steel bi-metal were manufactured using liquid–solid casting technology (Ramadan, 2015). The interfacial microstructure is highly affected by the liquid /solid volume. Good coherent multi-layers interfacial microstructure can achieve for all liquid/solid volumes of 16 to 24 by pouring liquid iron on 304 stainless steel solid plate.

For aim of improving the performance of the bi-metallic castings by control the bi-metal interface microstructures, the influence of annealing and normalizing heat treatment on the bi-metallic interface microstructures of 304 stainless steel and gray cast iron has been investigated. A different interface structures are obtained for all annealed and normalized samples. Annealing and normalizing heat treatment of interface microstructures of 304 stainless steel and gray cast iron induce a significant effect on the diffusion of both C and Cr elements and showing slightly effect on the diffusion of Ni element (Ramadan et al., 2017).

Also, heat treatment process for ductile cast iron/304 stainless bimetal casting has investigated. The results show that annealing at 720 ^{0}C has a significant effect on the interface layers structure. Three layers of interface structure are obtained after 180min annealing time instead of four due to the complete dissolving of thin layer of ferrite and multi carbides. Pearlite phase layer is transformed to spheroidal shape instead of lamellar shape in as-cast bi-metals. The significant carbon diffusion due to annealing affects the hardness of interface layers of ductile cast iron/304 stainless bimetal castings (Ramadan, 2018).

3.4. Bearing layer casting

Babbitt is commonly used in bearing materials as a lining in metal bearings. Babbitt is defined as an alloy of tin (Sn) and/or lead that containing copper (Cu), and antimony (Sb). The Babbitt and steel shell metals interface bond can be performed by chemical or mechanical methods. For aim of improving the interface bond to increase its performance, some of researches (Fathy 2018; Fathy and Ramadan, 2018) have been performed. Effect of glycerol and petroleum jelly additions during the tinning process of steel shell of Babbitt-steel bimetal is studied. Interface layer morphology is changed from a discontinuous layer in case of using flux + tin to a continuous layer by adding glycerol or petroleum jelly to the flux + tin mixture. Moreover, the interface layer thickness and the unbonded interface area increase with adding glycerol or petroleum jelly to flux + tin mixture (Fathy, 2018).

Effect of volume ratio of liquid to solid and pouring temperature on interface structure of cast Babbitt-steel bimetal composite was evaluated. Babbitt microstructures are improved and become finer with low pouring temperature of 380 ^{0}C. Increasing the volume ratio of liquid to solid decreases the Sn-Pb interface thicknesses resulted in increasing the bonded interface area. Volume ratio of liquid Babbitt to solid steel should be higher value that could be more than 5 times in order to optimize the production of Babbitt-steel bimetal composite at low pouring temperature (Fathy, 2018).

The future new research areas of bi-metal casting are concerned with the design and processing of light weight (mainly Al-alloys) high Performance (wear, heat, thermal chock resistant) automotive engine pistons. The using two different alloys will enable us to get the best properties of each. The future research should extensively focused on the optimizing the manufacturing process techniques in order to get high performance automotive engine pistons.

4. Conclusion

Bi-metal casting processes have been developed over the years resulting significant changes in ferrous and non-ferrous industry. Bi-metal casting processes have two main classifications: Liquid-solid configuration and Liquid-liquid configuration. Depending on the manufacturing method, the bi-metallic components of the hammer or ball mills are cast in material configurations of the Cr- cast iron working layer with a low-carbon cast steel base.

The bi-metallic material can be fabricated by bonding, similar and dissimilar materials, the limitation of its manufacturing process still hinder its fast development. Improvements of these technologies will continue for achieving the best performance, in production of spear part for corrosion, bearing and erosion resist. In this review, new trends and developments of bi-metal casting have been reported. However, there are still many future challenges for developing bi-metal casting industry in order to increase bi-metal quality, its performance and decrease its production cost.

Compliance with ethical standards

Conflict of interest

The authors declare that they have no conflict of interest.

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