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Study on fragmentation and dissolution behavior of carbide in a hot-rolled hypereutectic high chromium cast iron

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ABSTRACT

A sandwich-structured composite containing a hypereutectic high chromium cast iron (HCCI) and low carbon steel (LCS) claddings was newly fabricated by centrifugal casting, then the blank was hot-rolled into composite plate. The carbide fragmentation and dissolution behavior of the hot-rolled HCCI were analyzed. During hot rolling, significant refinement of carbides was discovered in hot-rolled HCCI specimens. The carbides were broken and partly dissolved into the austenite matrix. The results show that carbides are firstly dissolved under the action of stress. There are grooves appeared at the boundaries of the carbides. The grooves reduce the cross section of the carbide. When the cross section of the carbide reaches to the required minimum critical cross section, the carbide breaks through the tensile force. After break, carbides continue to dissolve since more interfaces between the matrix and carbides are generated. The secondary carbides precipitated due to the dissolution are index as fcc and stacking faults parallel to the {1 1 1} are observed.

1. Introduction

High chromium cast iron (HCCI) is known as excellent wear-resistant materials [1], which has been widely used for wear-affected equipment operated under extreme conditions, such as facilities in the slurry pumping systems of the oil sands handling and mineral processing [2–7]. The exceptional wear resistance of HCCIs results primarily from the high volume fraction of hard $(Fe, Cr)_7C_3$ carbides, which helps to prevent the formation of graphite and stabilize the carbides [4,5]. However, the low impact toughness of HCCI is a fatal defect due to the existence of hard and consecutive carbides in the matrix. Heat treatments are used in hypoeutectic chromium white irons as a result of austenite to martensite matrix transformation to improve impact toughness and wear resistance [8]. However, this may still bring relatively few benefits in improving impact toughness especially in hypereutectic chromium irons with even larger amount of hard $(Fe, Cr)_7C_3$ carbides [9]. Therefore, the using of wear-resistant materials is severely limited under strong impact conditions due to high production cost and large brittleness [8]. To achieve HCCI with a combination of good wear resistance and high fracture toughness, studies are forced on how to make the hard carbides refine and isolate, as a result of reducing the fragmentation effect of the matrix.

Hanguang Fu et al. [10] reported the refinement mechanism of a HCCI containing 4.0 wt.% C and 20.0 wt.% Cr adding titanium element and niobium element. Rolling is an effective method to make carbides break, but there are few reports, since the carbide is a very brittle phase and it cannot undergo plastic deformation, it is easy to crack in hot-rolling process, especially for a hypereutectic chromium irons with even larger size of primary $(Fe, Cr)_7C_3$ carbides.

The sandwich-structured composites have been extensively employed as advanced structural and functional materials in many fields because of their unique physical and mechanical properties, which can be fabricated by metallurgical bonding two materials, similar or dissimilar [11–13]. The centrifugal casting technique is typically used to cast fine-grained materials with a very fine-grained outer diameter, owing to chilling against the mould surface [14–16]. Two materials, in particularly, can be cast easily together by simply introducing a second material during the process [15]. It is noted for the high quality of the results attainable, particularly for precise control of their metallurgy and crystal structure. Unlike most other casting techniques, centrifugal casting is chiefly used to manufacture semi-finished materials for further machining, rather than shaped parts tailored to a particular end-use [16]. Then, the semi-products are fed directly into the rolling mills at the proper temperature, above the recrystallization temperature [17]. It is reported that significant grain refinement can be achieved using large strain rolling (LSR) in an AM60 alloy [18].

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In this work, a composite containing HCCI core and LCS claddings was prepared via centrifugal casting and then hot-rolled into composite plates. HCCI can undergo appropriate plastic deformation. Meanwhile, with low strength and good flow ability at high temperatures, the LCS claddings could exhibit a "lubricating effect" in hot rolling process, which could ensure the macroscopic deformation of HCCI [8]. The microstructure evolutions of a hot-rolled HCCI, as well as the carbide fragmentation and dissolution behavior of the hot-rolled HCCI are mainly discussed in this paper.

2. Experimental procedures

The sandwich-structured composite containing HCCI core and LCS (Q235 steel) claddings was prepared by centrifugal casting, as shown in Fig. 1. The HCCI consists of 4.9 wt.% C and 23.0 wt.% Cr; while the LCS consist of 0.15 wt.% C. LCS and HCCI were pre-melted in a 120 and 60 kg-capacity medium frequency induction furnace, respectively. The casting process was carried out independently in a horizontal cantilever centrifugal casting machine (J512). LCS was poured firstly, then the HCCI was poured, then the LCS. The rotating speed of the mould when pouring each materials were 800 r/min, 850 r/min and 900 r/min, respectively. The pouring temperatures of LCS and HCCI measured by infrared thermometer were 1813–1833 K and 1733–1735 K, respectively. After poured, the sandwich-structured composite plant was cooled to room temperature. The thickness of the LCS claddings and HCCI core were 29 and 11 mm, respectively. One fifth of the sandwich-structured circle was machined by wire cutting, then heated up to 1443 K for 1.5 h using a 45 kW chamber furnace, hot-rolled at 1423 K through 1–3 passes with the pass reduction of 10% and air cooled to room temperature. The hot-rolled specimens were cutted by spark machine, polished and etched by a 4% nitric acid alcohol solution for 20–30 s. The microstructures and phase constituents of HCCI were determined using an optical microscope (OM), a scanning electron microscopy (SEM, XL30 ESEM-TMP) equiped with the energy dispersive spectroscope (EDS). Disc specimens 3 mm of hot-rolled high chromium iron in diameter by 1 mm in thickness were prepared from bulk material by spark machining. Each disc was wet ground on fine abrasive papers to a final thickness of 0.20–0.25 mm prior to dishing at −20 °C in a solution of 5% perchloric acid in ethyl alcohol. The perforated discs were examined at 300 kV in a Tecnai-G^2-F30 S-TWIN transmission microscope. Discs which had perforated regions enabling structural contrast to be seen were removed from the microscope and subjected to further thinning by ion beam bombardment using argon ions accelerated at 5 kV. Each disc was inclined at 3–5° to the ion beam in order to thin down as evenly as possible the wedge of material around the original dished perforation. During specimen preparation a number of problems were encountered, these included preferential thinning of either the matrix or carbide phases, attack at the eutectic carbide-matrix interfaces and removal of eutectic carbides.

3. Results and discussion

3.1. The effect of hot rolling on the carbides of HCCI

Fig. 2 shows the effect of hot rolling on the carbides of HCCI. Fig. 2a depictes the microstructures of HCCI before rolling. As one can see, primary carbides were hexagonal or irregular polygon blocks distributed in the matrix, the carbides were with different sizes, ranging from 15 to 70 μm. Some of the carbides were seen to contain a central core of matrix constituent which in a few cases was connected to the matrix surrounding the carbide. The observed sizes of the cores varied from 2 to 4 μm and did not appear to relate to the overall diameters of the enclosing carbide rods. Eutectic carbides were continuous slender-shaped rod with different distributions in the matrix. Some were paralleled to each other, some were radial distributed around the primary carbides. Notice that certain eutectic carbides were attached to the primary carbides. It is considered that the continuous fragile carbides reduced the continuity of the matrix, resulting a low impact toughness. Fig. 2b–d shows the microstructures of HCCI through the deformation of one, two and three rolling passes, respectively, then air cooled to room temperature. After hot-rolled through one pass, there was no obvious break of carbides. The shape of the primary carbides became irregular, no obvious change of the size was observed. The cores within the primary carbides enlarged. The observed sizes varied from 8 to 22 μm. Gavriljuk et al. discussed the decomposition of cementite in pearlitic steel due to plastic deformation, proved the dissolution phenomenon of the hard phase in the process of deformation [19]. Thus, the enlargement of the cores within the primary carbides indicated that dissolution might occur during hot deformation. The shape of eutectic carbides changed obviously. There were fishbone-shaped eutectic carbides connected to each other distributed around the primary carbides. Rod-shaped eutectic carbides with curve surfaces were also observed. Certain eutectic carbides were also attached to primary carbides. After two rolling passes, the carbides were also continuous, and partly connected to each other. It was clearly observed that primary and eutectic carbides became round. The size of primary carbides did not change obviously. Cores within the primary carbides continued to enlarge, showing that dissolution might be stronger. Notice that grooves appeared at the edge of certain primary carbide. It indicated that the carbides were partially dissolved. There were worm-like shaped eutectic carbides distributed around the primary carbides, but the eutectic carbides were with no connection to the primary carbides already. Primary carbides and part of eutectic carbides were isolated through rolling force. After three rolling passes, carbides fragmentation became more obvious. Eutectic carbides were almost broken into small isolated particles, diffusely distributed into the matrix. The size of eutectic carbides were ranging from 2 to 15 μm. Moreover, the amount of carbides increased obviously. The carbides were broken into pieces.

3.2. Fragmentation of carbides during hot rolling process

During hot rolling process, it is considered that tensile fracture is the broken form for the carbides. This is proved by Xing shuming et al. who discussed the behavior of carbides in white cast iron during hot deformation [20]. This phenomenon can be observed in Fig. 2d. In the hot rolling deformation, austenite occur plastic deformation first, then a frictional force (F) generate from the interface between austenite and carbides, which can be calculated as follows:

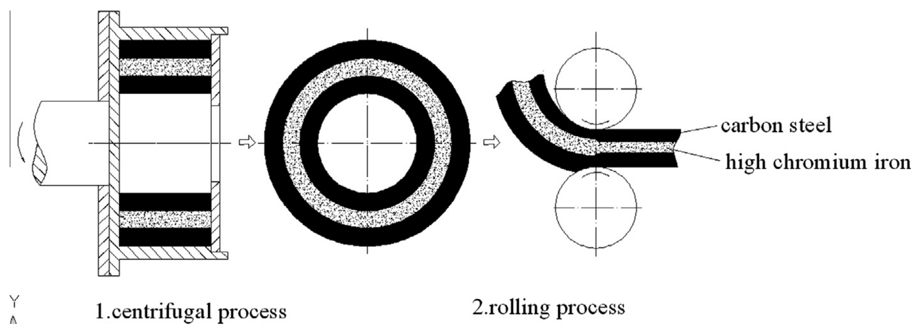

Fig. 1. The schematic diagram of the centrifugal casting-hot rolling process.