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Additive billet and FGS forging for large forgings

B. Wang, D. Zhao, Y. Liu, Y. Nie, X. Zhang, R. Wen

This paper introduces a series of transformative innovation in blank preparation, forming method and facilities development of large forgings carried out by China First Heavy Industries (CFHI) since the Austria Annual Meeting in 2017. In order to promote the high quality development of large forgings, CFHI has set up a research team for transformative innovation in manufacturing technology of heavy and
high--end complex forgings, and innovatively proposed new concepts such as additive billet, effective substrate and FGS forging. Through the basic theory research and engineering practice verification, the paper discusses in detail the additive billet which systematically solves the problems of segregation, inclusion and harmful phase and the FGS forging which systematically solves the problems of low material utilization rate, mixed crystal and crack caused by tensile stress. In addition, double super round billet vertical semi-continuous casting machine, innovative application of casting billet and super large multifunctional hydraulic press which are closely related to the full implementation of the two original technological routes of additive billet and FGS forging are described.

KEYWORDS: ADDITIVE BILLET, EFFECTIVE SUBSTRATE, DOUBLE SUPER ROUND BILLET, FGS FORGING, SUPER LARGE MULTIFUNCTIONAL HYDRAULIC PRESS

INTRODUCTION

With the continuous development of major equipment, higher requirements have put forward for large forgings. Not only are the specifications and sections getting bigger and the internal qualities are improving. For example, the development trend of nuclear power forgings is large-scale and integrated[1]. The traditional manufacturing method of large forgings is different meet the above requirements. It is well known, that there are serious problems of segregation, inclusion and harmful phase in the traditional preparation of large ingot. In the traditional plastic forming process of large forgings, there are same problems such as low material utilization rate, mixed crystal and crack caused by tensile stress[2].

In order to systematically solve the above problems, CFHI has set up a research team for transformative innovation in manufacturing technology of heavy and high-end complex forgings and innovatively proposed new concepts such as additive billet[3], effective substrate and FGS forging[4]. Through in-depth basic theoretical research and a lot of engineering practice, the connotation and extension of additive billet and FGS forging are expounded. In order to better implement additive billet

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and FGS forging, a vertical semi-continuous casting machine with double super round billet for preparing the effective substrate was developed, an innovative idea of preparing super long casting billet into forging billet then applying it in different sections was put forward, and various preparatory works such as structure selection, technology and construction design, manufacturing process of key parts and installation process of super large multifunctional hydraulic press were completed.

ADDITIVE BILLET

Additive billet is an original large forging billet preparation technology that uses additive manufacturing model to cover the effective substrate with liquid steel or to compound the effective substrate with each other, and makes binding interface healing and microstructure homogenization of composite billet. The pictures explanation of additive billet is shown in Fig.1.

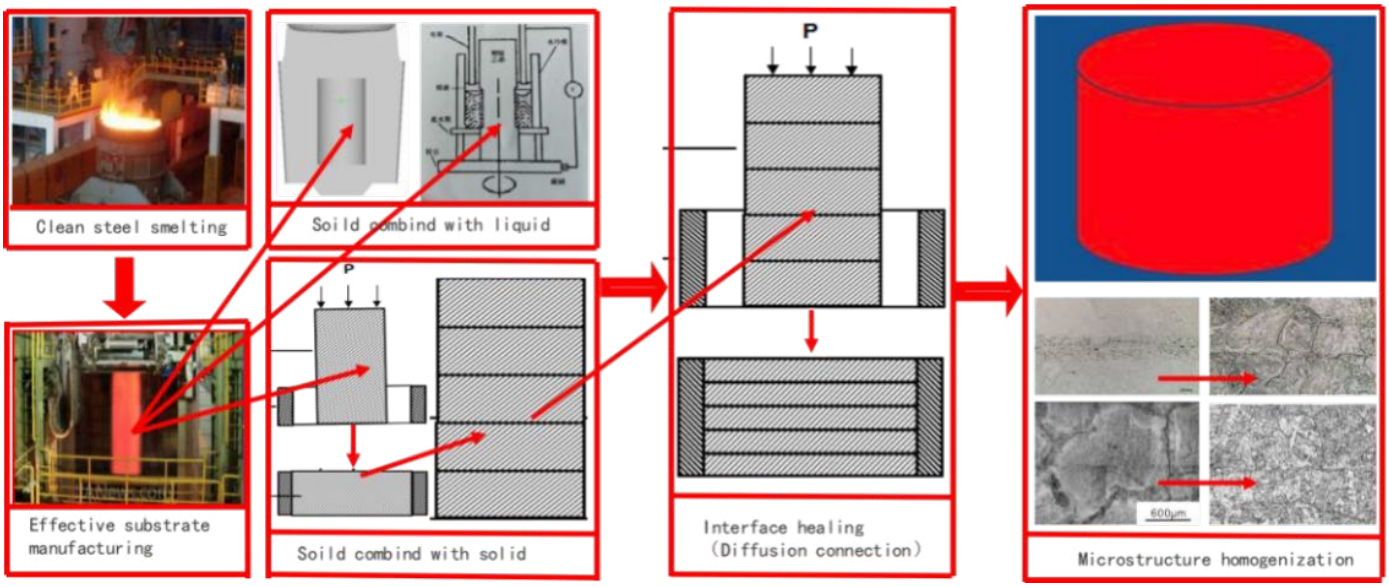

Fig.1 - The pictures explanation of additive billet.

As we all know, different material, different preparation methods of ingot or billet, all correspond to an optimal solidification cross-section. We refer to the ingot or billet that has no unacceptable casting defects and can obtain maximum solidification cross-section as the effective substrate. Fig.2 to Fig.4 are typical cases of basic theoretical research and experimental verification of additive billet.

Fig.2 shows the scale experiment of additive billet for back-up roll. In order to fully cover the round billet (similar to the effective substrate) with liquid steel, a low melting point support is welded to the round billet (see Figure2a) and the round billet is suspended in the ingot mold (see Figure2b). The low melting point support material is completely melted during the solidification process of the molten steel, which can effectively avoid the oxidation of the composite interface during the heating process before healing. Due to the "liquid-solid" composite under vacuum, and the composite interface is isolated from the atmosphere after pouring, the composite effect is good, and there are no visible defects (see Figure2d). After the healing of the composite interface and the microstructure homogenization of the composite billet (see Figure2e), the metallographic microstructure test result (see Figure2f) can fully meet the conditions for manufacturing the billet required for back-up rolls.

Fig.2 - The scale experiment of additive billet for back-up roll.

Fig.3 shows the engineering practice of increasing the diameter of back-up roll by means of additive billet making. Multiple electrodes are distributed in rings around the effective substrate, as shown in Figure3a. The diameter of back-up roll billet was increased by ESR, as shown in Figure3b. In the process of ESR, not only the electroslag steel melt the surface of effective substrate (the melting layer is generally controlled by 3~5mm), but most of the melted surface oxides can also be eliminated with the slag. The compound effect after increased diameter is very ideal, as shown in Figure3c

Fig.3 - The engineering practice of increasing the diameter of back-up roll.

FGS FORGING

FGS forging is an original forging technology which combines forming, grain and stress organically in the visual state at the same time, and uses a combination die to make the forging billet near net shape forming under multidirectional compressive stress, so that the forging can obtain uniform and fine grain. Table1 shows the research content of FGS forging. Visualization in FGS forging includes changes in the external shape and internal structure of the forgings. Visualization technology in FGS forging is under development. The external shape change of forgings can be displayed by the signal collected by several sensors mounted on the hydraulic press and the die. The internal structure change model of forgings is established based on the numerical simulation of structure evolution repeatedly optimized by the results of forgings anatomical inspection.

Fig.4 shows the engineering experiment of FGS forging for cold rolling work roll made of continuous casting billet with diameter of 600mm. The goal is to replace the free forging of ESR ingot. There are crack, shrinkage hole and network carbide in the core of continuous casting billet, as shown in Figure4a to 4c. After FGS forging, the continuous casting billet containing almost all casting defects obtained grade 8 grain and carbide dispersed in both the roll neck with large extrusion ratio and the roll body with small extrusion ratio , as shown in Figure4d to 4g. Therefore, the cold rolling work roll passes the rigorous surface wave detection very smoothly. This FGS forging method for shaft forging has also achieved very good results in the application of large section Ni-based alloy rotor[5] and super-alloy fine grained bar, as shown in Fig.5.

Tab.1 - the research content of FGS forging.

THE RESEARCH CONTENT OF FGS FORGING						
Research content	Shaft forging extrusion forming	Forging with nozzle head integrated forming	Integrated forming of cylinder forging with nozzle	Other forging integrated forming	Lightweight and easy to assemble and disassemble combination mold	Visualization
Research approach	Numerical simulation;scale test;Industrialization					Numerical simulation;
						Anatomical verification
Development target	Rotor roll	Channel head Mono bloc up Head with quick lock	Integrated nozzle shell	Pump shell Main pipe	The inner mold is divided;the outer mold is universal;easy to assemble and disassemble	Guide production and lay the foundation for intelligence

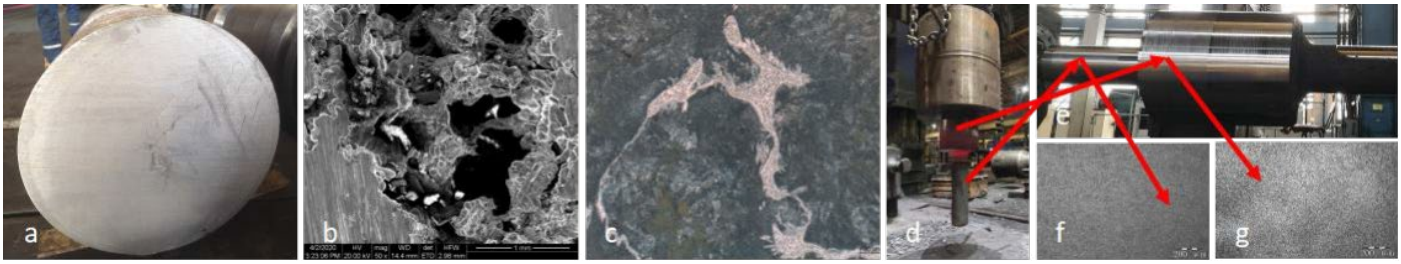

Fig.4 - The engineering experiment of FGS forging for cold rolling work roll.

Fig.5 - The engineering experiment of FGS forging for IN617mod1 and IN718.

Fig.6 shows the combination die used for FGS forging and the forgings after removing the combination die. Figure 6a is the CAP1000 stainless steel forged pump shell; Figure 6b is the nozzle of CPR100 main pump; Figure 6c is the trouser shaped tee for the 600MW fast reactor pressure pipe.

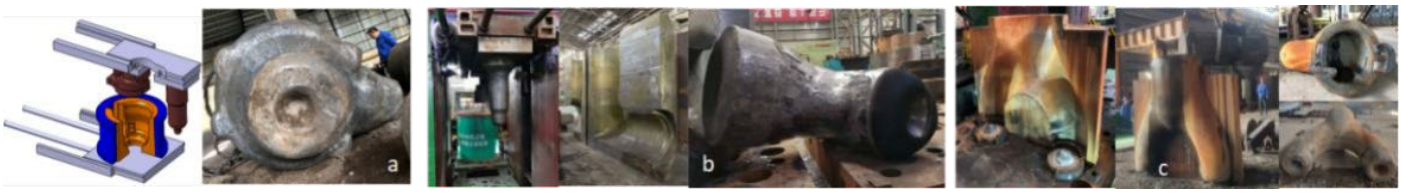

Fig.6 - The combination die used for FGS forging.

NEW FACILITIES

In order to popularize the original technology of additive billet, CFHI led to development a double super round billet vertical semi-continuous casting machine. Double super means that the diameter of 1600mm vertical semi-continuous casting machine exceeds the largest continuous casting or semi-continuous casting machine diameter in the world, and the length greater than 12500mm exceeds the maximum cutting length of the continuous casting machine. The application of double super round billet is shown in Fig. 7. Because the surface quality of double super round billet is better than that of die cast ingot, the problem of inclusions being exposed on the surface of back-up rolls or rotors can be completely solved.

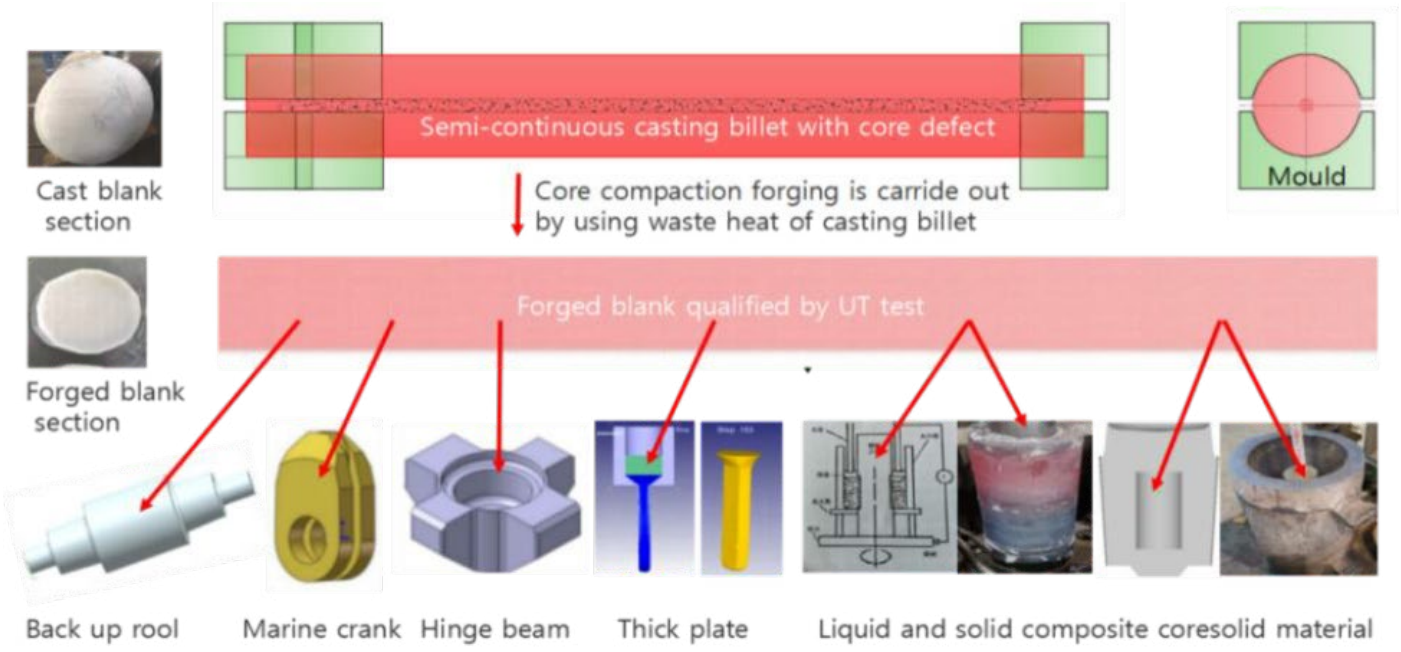

Fig.7 - The application of double super round billet.

In order to promote the application of the original FGS forging, CFHI intends to build a super large multifunctional hydraulic press[6]. After more than five years of in-depth research, has completed the structure selection, technology and construction design, 38 key parts of the casting, forging, machining and welding process preparation, developed the installation process and commissioning program.

CONCLUSION

(1) Additive billet is an effective way to systematically solve the serious segregation, inclusion and harmful phase of large ingot with hard to deform metal.

(2) FGS forging is an effective way to systematically solve the problems of low material utilization rate, mixed crystal and cracks caused by tensile stress in the plastic forming process of hard to deform metal.

(3) The semi-continuous casting machine and super large multifunctional hydraulic press are a favorable guarantee for better implementation of the two original technologies of additive billet and FGS forging.

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