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Review

Application of Aluminum Alloy Semi-Solid Processing Technology in Automobile: A Review

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Abstract: Semi-solid processing technology is a new forming technology for aluminum alloy components, which has advantages in producing high-quality components with complex shapes. Several methods of semi-solid metal preparing and forming have been developed in the past 50 years. Some methods have been applied to provide high-quality components or improve castings' quality in the field of automobile. This paper reviews the development and application of semi-solid processing technology and discusses about its future application prospects.

Keywords: semi-solid processing technology; aluminum alloy; application; automobile

1. Introduction

In recent years, automobile manufacturers, especially new energy automobile manufacturers, have paid more and more attention to automobile light weighting as it is beneficial to saving energy, reducing exhaust emissions, and lowering comprehensive manufacturing cost. Replacing iron and steel components with aluminum alloy components can significantly reduce the body weight of a vehicle because the density of aluminum alloy is only about 1/3 of that of iron or steel. However, a challenge for increasing the aluminum consumption in automobiles is that both of the strength and elastic modulus of aluminum alloy are usually lower than those of iron and steel, which leads to a higher quality requirement on aluminum alloy components than iron and steel components.

The aluminum alloy components are usually fabricated by plastic deformation processes (e.g., rolling, extruding, punching, and forging) or casting processes (e.g., sand casting, permanent mold casting, lost foam casting, and high pressure die casting). The plastic-formed components have good quality and performance, and can be used under high stress conditions. However, the plastic forming processes cannot be used to produce components with complex shapes. Although the casting processes can be used to produce components with complex shapes, the quality and performance of cast components are usually lower than those of plastic formed components due to the occurrence of casting defects. Therefore, developing and producing high-quality and complex-shaped aluminum alloy components is still a big challenge for automobile components suppliers.

Semi-solid processing technology is a new forming technology for aluminum alloy components, which originated from Massachusetts Institute of Technology in 1970s [1,2]. In this process, alloys are prepared into solid-liquid mixed state which is called semi-solid metal. In semi-solid metal, solid particles, which are spherical or nearly spherical, suspend in liquid metal. Compared with liquid metal, semi-solid metal has special rheological property, flow behavior and solidification behavior [3,4]. Under shear stress, semi-solid metal can flow like liquid and the fluid viscosity of semi-solid metal decreases as the shear stress increases.

Therefore, the semi-solid metal can be cast like liquid metal and formed into complex-shaped components. Moreover, the quality of semi-solid processed components is much better than that of cast components and close to the quality of plastic formed components. Therefore, semi-solid processing technology has been used to produce high-quality castings without defects or improve the quality of castings in the fields of automobile, motorcycle, bicycle and telecommunication equipment [5–7].

2. Development of Aluminum Alloy Semi-Solid Processing Technology

2.1. Semi-Solid Metal Preparing

There are two routes to preparing semi-solid metal. One is partial melting solid metal route (thixo-route) and the other is partial solidifying liquid metal route (rheo-route).

In the thixo-route, raw material is treated by a special technology to obtain non-dendritic aluminum grains and then reheated to semi-solid temperature range. The special technology is categorized in two types as listed below.

Type I. Special technology acts on melt solidification in the production of raw material. The raw material has near-spherical or rose-like aluminum grains which evolve into spherical particles after reheating. This type of technology includes magneto-hydro-dynamic stirring (MHD) [8–10], spray forming (Ospray) [11,12], cooling slope (SC) [13] and others.

Type II. No special technology works in the production of raw material and the raw material has dendritic aluminum grains. The raw material is treated with plastic deformation process to break the dendritic aluminum grains. After reheating, the broken aluminum grains evolve into spherical particles. This type of technology includes Strain-Induced Melt Activation (SIMA) [14–17], Recrystallisation and Partial Melting (RAP) [9,13,18], Equal-Channel Angular Pressing [19] and others.

In the rheo-route, raw material is melted and then treated by the special technology to obtain spherical or near-spherical aluminum particles directly. The special technology includes Swirled Enthalpy Equilibration Device (SEED) [20–23], Enthalpy Control Process (ECP) [24,25], Gas Induced Semi-Solid (GISS) [26–30], Rapid Slurry Formation (RSF/RheoMetal) [31–33], Cooling Slope (CS) [34–36], Air-Cooled Stirring Rod Device (ACSR) [37–39] and others.

Typically, the thixo-route is suitable for preparing semi-solid metal with solid fraction above 50%, and the rheo-route is suitable for preparing semi-solid metal with solid fraction below 50%. Besides, both of the process energy consumption and the cost of the thixo-route are higher than that of the rheo-route. Therefore, the rheo-route is the focus of the development of semi-solid metal preparing technology since the early 2000s. SEED, GISS, RSF and ACSR have been used to produce automobile aluminum alloy components.

2.2. Semi-Solid Metal Forming

The semi-solid metal forming technology has been developed for more than 50 years since the special rheology of semi-solid metal was discovered. Lots of work has been tried to form semi-solid metal with different processes, including forging, extruding, high pressure die casting (HPDC), sand casting, permanent mold casting and other processes. Among these processes, thixo-forging, rheo-forging, thixo-HPDC and rheo-HPDC were already developed and successfully applied in industry. In the thixo-forging and thixo-HPDC, semi-solid metal with solid fraction of 50–70% is prepared by thixo-route. In the rheo-forging and rheo-HPDC, semi-solid metal with solid fraction less than 50% is prepared by rheo-route. Typically, HPDC process has more advantages than forging process in component shape complexity and production efficiency. Therefore, semi-solid HPDC is more suitable for producing automobile components with complex shapes.

It is noteworthy that the additive manufacturing technology of semi-solid metal has become a research hotspot in recent years. The research teams in Southern University of Science and Technology (Shenzhen, China), Lawrence Livermore National Laboratory (Livermore, USA) and University of Campinas (Campinas, Brazil) have made great progresses in laboratories [40,41]. This new technology will support producing hollow-structure components which have significant weight reduction effects.

3. Application in Automobiles

The commercialization of semi-solid processing technology in automobiles has risen in USA and Italy

since the 1990s. Thixo-forging and thixo-HPDC were mainly used from the 1990s to the 2000s. Since the 2010s, the application of semi-solid processing technology has grown rapidly in China and rheo-HPDC has become the mainstream process.

3.1. Producing High-Quality Components

One approach of semi-solid processing technology applying in automobiles is to produce high-quality aluminum alloy components. The components fabricated by semi-solid processing with high solid fraction are free from defects or within a low level of defects, which can meet the high-quality requirements of automobile. Moreover, the components can be heat treated at high temperatures because there are no gas bubbles in components [42]. After heat treating, the components have better mechanical properties which are close to the mechanical properties of iron and steel components. Thus, it becomes possible to reduce weight by replacing iron and steel components with aluminum alloy components.

The research teams in General Research Institute for Non-ferrous Metals (Beijing, China) and Southern University of Science and Technology (Shenzhen, China) have developed a complete set of semi-solid processing technology based on the SEED and provided technical support for manufacturers in China. Sliver Bases Die-Casting (Shenzhen, China) has used the semi-solid processing technology to produce aluminum alloy automobile components, such as torsion supports, control arms, brake calipers, air chamber brackets, left-middle brackets and shock absorption towers [43]. The weight of the aluminum alloy components can be reduced to about 35–55% of the iron or steel components.

Kovolis Hedvikov (Hedvikov, Czech Republic) also used SEED rheo-HPDC process to produce engine brackets using AlSi7Mg0.3 alloy for Puretech Motor [44]. The components were made by conventional HPDC process using AlSi9Cu3(Fe) alloy earlier. The application of semi-solid processing technology decreased the weight of components by 33% and increased the mold life by 50%.

SAG Fueltech Sweden (Ronneby, Sweden) used RheoMetal rheo-HPDC process to produce CAB mounts and Muffler brackets using TX630 aluminum alloy for Volvo Trucks [33]. The components were T5 heat treated. The application of semi-solid processing technology improved the fatigue performance of components and increased the cost efficiency in casting.

3.2. Improving the Quality of Castings

Another approach of semi-solid processing technology applying in automobiles is to improve the quality of aluminum alloy castings. Compared with the conventional HPDC, semi-solid HPDC has significant advantages in reducing defect contents, including gas bubbles, shrinkage and tear cracks.

GISSCO (Thailand) and its collaborators used GISS rheo-HPDC or rheo-forging to produce pump bodies, cases, lowers, oil coolers, oil pans, housings, ladder frames, wheels and crank cases [45]. Runxingtai Electrical Equipment (Zhuhai, China) used ACSR rheo-HPDC to produce components of new energy vehicles, such as power converters, electric control system parts, reducers and motors [46].

4. Discussion

Semi-solid processing technology has been used in automobiles for more than 30 years. But this technology possesses a relatively small application scale compared with plastic deforming processes and casting processes. The deepening needs of automobile lightweight will provide very good opportunities for the application explosion of the semi-solid processing technology due to its advantages in producing high-quality and complex-shaped aluminum alloy components.

Until now, the applications of this technology in automobiles are limited to the vehicle chassises and engine parts. With the rising demands of super-large automobile body parts with lighter weight in electric vehicles, the semi-solid processing technology can take these opportunities in automobile body parts manufacturing. The semi-solid processed parts can be welded, while most of casting parts cannot because of the defects such as gas bubbles. The welding capability of semi-solid processed parts provides a new method of producing super-large automobile body parts. The large-sized body parts can be divided into several medium-sized parts. The medium-sized parts can be produced by semi-solid process with high quality, and then welded together. Compared with ultrahigh vacuum die casting process, this new method can avoid the

huge cost caused by using the super-large die-casting machines and molds, as it becomes unnecessary to use those large machines. Besides, this new method can reduce the development time and cost, extend the life of molds, and improve the quality and performance of final welded parts.

5. Conclusions

Semi-solid processing technology has been developed for more than 50 years. Several semi-solid metal preparing and forming methods have been invented. SEED, GISS, RSF and ACSR rheo-HPDC processes have been applied to produce high-quality components or improve the quality of castings in automobiles. The application scale of semi-solid processing technology in automobile will burst with the deepening needs of automobile lightweight. The technology also has the application prospects in producing large automobile body parts.

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