Ultra-Large Aluminum Castings in Automobiles

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Abstract: Ultra-large aluminum castings are increasingly used in automobiles, particularly in electric vehicles for light-weighting and manufacturing cost reduction. As most of them are structural components subject to both quasi-static, dynamic and cyclic loading, the quality and quantifiable performance of the ultra-large aluminum castings is critical to their success in both design and manufacturing. This paper reviews applications of ultra-large aluminum castings in automotive industry and outlines their advantages and benefits as well as challenges. Factors affecting quality, microstructure and mechanical properties of the ultra-large aluminum castings are evaluated and discussed.

Keywords: Ultra-Large Castings; Aluminum; Light-weighting; Quality; Microstructure; Materials Properties

1 Introduction

According to Ducker [1], applications of aluminum castings in automobiles have grown up by more than 300 pounds per vehicle (100%) in past twenty years. Recently, automakers have introduced ultra-large aluminum castings in critical structures to integrate tens or hundreds of different parts into a single piece casting. For instance, Tesla uses front and rear aluminum giga castings in the model Y vehicles [2]. GM has used 6 mega aluminum castings to form the entire lower body structure for the Cadillac Celestiq vehicle, Fig. 1 [3]. Toyota plans to implement giga castings to significantly reduce the number of parts used in its front and rear body frames [4]. Many other automakers are taking the similar approach.

Ultra-large aluminum castings require good quality, high properties, and predictable performance. These goals are made more challenging by the complexity of ultra-large casting geometry and subsequent processing. The aluminum casting quality and final product performance is determined by alloy composition, melt treatment, casting and gating system design, and particularly casting process. Therefore, it is critical and economically important to design and manufacture the ultra-large castings correctly.

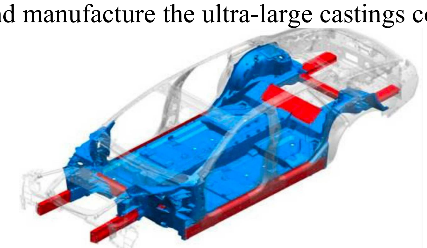

Fig.1. Six mega Al castings in Cadillac Celestiq [3].

2 Opportunities and Challenges

Ultra-large aluminum castings offer great opportunities and benefits including reducing number of parts (60+), saving tooling cost (>40%), saving energy (>30%), saving mass (>30%), reducing lead time, and broadening applications. There are also challenges associated with the ultra-large aluminum castings such as dimensional stability, sustainability, repairability and serviceability, and particularly difficulty in making quality casting.

3 Key factors affecting quality of ultra-large aluminum castings

Cast aluminum alloy

With the long metal flow length in the ultra-large casting, cast aluminum alloy shall have much better castability including high fluidity and low shrinkage and hot tearing tendency. In addition, the alloy should have limited aging response to balance dimension stability and yield strength requirements. Currently, C611 and Aural 5 alloys are mainly used in high pressure die casting (HPDC) giga castings. Both alloys have about 7% Si and low Fe (<0.2%). Tesla uses AA386 alloy which has high Fe content (<0.5%) and small amount of Cu (up to 0.8%).

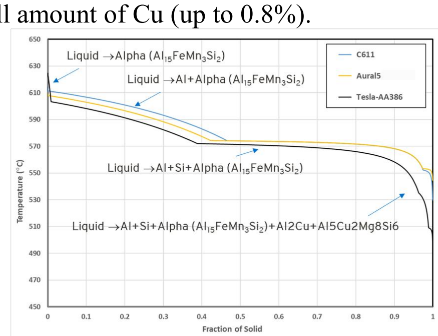

Fig.2. Calculated fraction of solid and solidification sequences of three alloys.

The Cu in the alloy increases freezing range (Fig. 2), porosity and crack susceptibility coefficient. It also decreases corrosion resistance. GM developed a sustainable alloy called UniCAST which is good for structure casting [5].

Melt cleanliness control

Liquid aluminum cleanliness is vital to produce high-quality castings since most defects in final casting are usually related to inclusions and gases coming from the liquid metal. The liquid metal should be cleaned to the highest level possible before it is introduced into mold cavity. One technology was reported from GM to reduce liquid metal contamination with scrap return charge [6]. The method includes coating the scrap charge with a layer of flux that can help remove oxides from the scrap charge surfaces and meanwhile provide a cover flux to protect the melt bath from oxidation.

Gating system design

The optimal design of gating system can significantly reduce the turbulent flow of the molten metal, minimizing the amount of gas and trapped impurities. For production of quality aluminum castings, the design of a naturally pressurized gating system shall be used. Melt velocity at any time during mold filling should be kept below the critical velocity of 0.5 m/s. For HPDC, however, mold filling needs to be completed within 100-200 milliseconds to be able to fill up the thin walls. The minimum melt velocity at ingates is usually controlled around 40 m/s, which is 80 times greater than the critical velocity. Therefore, it is vital to correctly design HPDC gating system and particularly ingate locations and sizes to avoid converging melt fronts.

Mold surface treatment

Mold surface condition determines not only the quality of the surface finish but also the quality of the casting skin layer that can significantly affect casting durability performance as fatigue cracks usually form from the casting surfaces. Castings with relatively large flat surfaces can experience excess surface appearance and quality issues due to the formation and entrapment of young oxides in the melt front during filling. Mold/die surface should be treated with unique surface patterns or texture so that the oxide film in the metal front can be peeled off during mold filling, improving surface quality.

Casting process

Casting process optimization and control is so important to the casting quality particularly for the ultra-large aluminum castings. Casting process parameters such as mold/die temperature, melt pouring temperature, and shot profile should be aligned with the gating system design for optimal results as a given gating design literally determines process parameters.

For a given size of casting, there is an ideal/optimal mold temperature to achieve a good combination of best casting quality and prolonged die life although it is generally accepted that the ideal die temperature should be kept about one third of the melt pouring temperature. The actual ideal mold temperature should be determined and optimized using a casting process simulation code incorporating with a thermal imaging technique.

Pouring temperature influences both metal flow and casting quality and mechanical properties. Although typical pouring temperature is adapted to be around 50-100 °C higher than the alloy liquidus, comprehensive casting process simulations are needed to determine the optimal pouring temperature, particularly for the ultra-large castings due to longer metal flow distance.

In HPDC, shot profile is very critical as it determines final casting quality such as trapped air and oxide entrainment. Fig. 3 compares the calculated accumulation of trapped air for four combinations (two gating designs and two shot profiles). The delayed plunger fast speed stage and pressurization (shot profile 2) significantly reduces the trapped air with gating design 2.

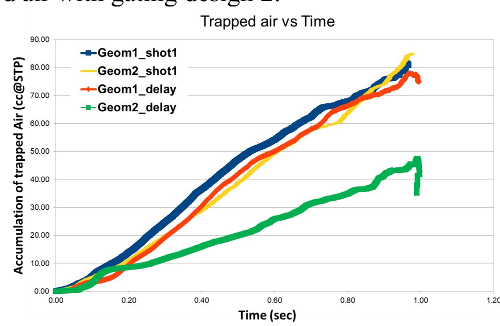

Fig.3. Accumulation of the trapped air calculated for different shot profiles.

4 Conclusion

Application of ultra-large aluminum castings in automobiles has brought great opportunities and posed challenges that can be addressed with the advanced metal casting technologies and virtual casting tools.

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