Integrated Structural Casting Development with Digital Twin Technology

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Abstract: In the present paper, we introduced the development of integrated structural castings with digital twin technology for the rear structure of high-end E-sports cars. The topological optimisation, casting structural design, materials verification, melt flow and solidification, mechanical property prediction and the final verification using low pressure die casting (LPDC) for the component manufacturing are described in details for digital twin. The microstructures and mechanical properties of the casting with satisfied quality are described under heat-treated condition.

Keywords: aluminium alloys; casting; microstructures; mechanical properties; digital twin

1 Introduction

Aluminium alloys are being increasingly used as lightweight materials in transport since weight reduction has been proved as one of the most effective and efficient approaches to improve energy consumption and reduce CO_2 emissions [1, 2]. Castings of aluminium alloys are critical and important for geometrically complex parts. Because of the high temperature and complex process during casting, recognition and using potentials for property improvement of lean structures before the components are produced will be extremely significant for product development. As a new development technique, digital twin is now reliable for the smart development of the manufacturing process of how to make a component from scratch and considering all process steps until dispatch, but still rare in the applications in casting manufacturing. In the present study, we introduced the digital twin assisted development of integrated structural castings for the rear structures of high-end E-sports cars.

2 Experimental procedure

A356.2 alloy was used for manufacturing castings using a low pressure die casting (LPDC) machine, with a locking force of 24 tonne and a plate size 1.9 m × 1.6 m, made by LPM (Italy). The pressure was set as 0.8 bar during casting. The tensile tests were conducted following ASTM E08/E08M, using an Instron 5500 Universal Electromechanical Testing System equipped with Bluehill software. The gauge length of the extensometer was 25 mm and the ramp rate for extension was 2 mm/min. The microstructures of cast components were checked using a Zeiss optical microscope with quantitative metallography. Digital twin including melt flow, solidification and mechanical properties prediction was conducted using Magmasoft with specially developed modules.

3 Results and discussion

The computational procedures used to create the digital twin included gating development, melt filling and solidification with structural optimization, the prediction of microstructures and the mechanical property under as-cast and as-heat treated conditions, the validation of digital results with casting samples for geometry tolerance and mechanical properties.

Figure 1 shows the full design procedure for topological optimisation of the integrated casting structure for rear chassis structures. This holistic design approach includes the separation of subframe, all the hardpoints for suspension links on the same casting, the connection of upper and lower castings for better integration, the increase of webs for hardpoint stiffness improvement, the incorporation of damper top and the definition of tolerance requirement, the incorporation in primary structure, the socketed longitudinal crush element and improved bond connection at front, the load path improvement for better crash load transfer, the casting manufacturability and primary feedback from flow analysis, the final optimised and refined structure.

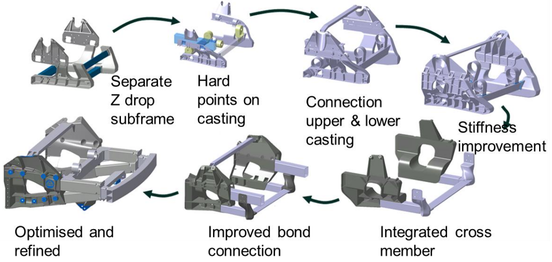

Figure 1 Topological design and optimisation of the integrated casting structure for rear chassis.

Figure 2 shows the materials modelling and verification, in which a standard casting structure widely used in OEMs was adopted. A356.2 alloy was melted using a standard procedure and cast into standard components. The tensile properties were then measured and analysed. From the digital analysis, the middle section of top flanges showed the yield strength from 243 to 246 MPa, UTS from 320 to 330 MPa and elongation from 8.2 to 8.7%. The verification casting in Fig. 2d was sampled at the same position of the middle section of top flanges. T6 heat treatment was conducted at 540 ºC/8 h for solution and 180 ºC/6 h for ageing. Table 1 shows that the yield strength and UTS were better than the digital prediction, but close each other. However, the elongation was slightly lower in the physical casting. Thus, it is important to satisfy the elongation in the real castings.

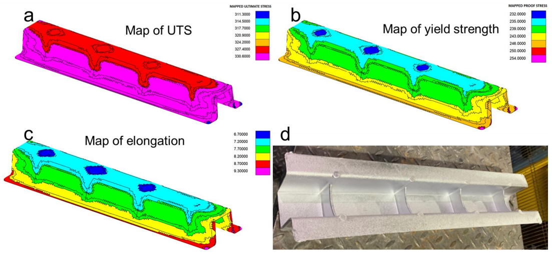

Figure 2 Materials verification of A356.2 alloy using a standard casting structure at auto OEMs.

Table 1. Tensile properties of aluminium alloys under T6.

	Yield (MPa)	UTS (MPa)	Elongation (%)
A356 T6	250±7	330 ±13	7±1.5

Figure 3 shows the casting defects in the digital analysis of the casting with optimised gating system for the melt flow, solidification and defect formation during casting. The results showed the design of gating system was superior, no obvious defects could be found in the key areas of castings and only tiny defects were found at the cross-section of ribs.

Figure 3 Simulation of casting defects after melt filling and solidification simulation of A356.2 alloy

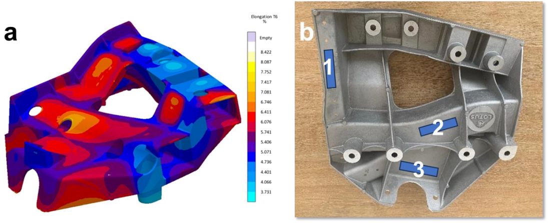

Figure 4 Digital twin of casting made by A356.2 alloy for (a) virtual simulation of elongation under T6, (b) physical casting made by LPDC with sampling for tensile test

Figure 4 shows the elongation prediction from digital analysis and the final verification of castings using LPDC. From Figure 4(a), the predicted elongation of the casting varied from 4.5% to 7.5% under T6 condition. The casting in Figure 4(b) was for the final verification of mechanical properties with the locations of sampling. The measured tensile properties of different locations are shown in Figure 5, in comparison with the elongation data obtained from prediction. Clearly, the elongation of tested sample was better than the prediction. As such, the safety factor should be higher in the castings, which can be used in industry.

The microstructure of the casting can be seen in Fig. 6, in which the dendrites with the size of 300-400 μm were formed under as-cast condition. After T6 heat treatment, the tips of dendrites were blunt and the eutectic Si phase was spheroidized.

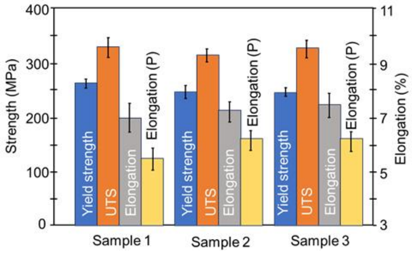

Figure 5 Tensile properties measured from verified casting and the data obtained from prediction (P) of A356.2 alloy

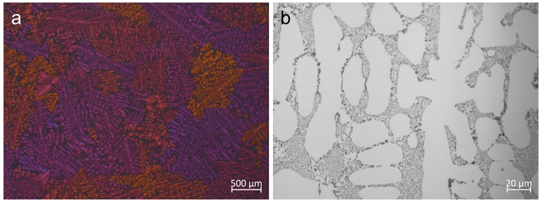

Figure 6 Microstructures in cast A356.2 alloy: (a) as-cast grain size; (b) morphology of primary α-Al phase after T6

4 Conclusion

The digital twin technique is capable of developing casting manufacturing from structural optimisation design to final mechanical properties. The gating system optimisation, melt filling, modification and defect formation, and the mapping of mechanical properties can be obtained from digital analysis with relatively accurate data. The casting verification of A356.2 tensile samples have a yield strength of 250 MPa, a UTS of 330 MPa and an elongation of 7%, which is close to the digital results.

References

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