

Development of a model for the prediction of mechanical properties for Al-Si-Mg castings

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A356 alloy is widely used to produce structural components by means of Low Pressure Die Casting (LPDC) process. Generally, a T6 heat treatment (solution, quenching and aging treatment) is carried out to improve the strength of the casting. Nowadays the simulation of casting processes and solidification phenomena is a common practice for designing sound castings. However, mechanical strength values and their correlation with microstructure parameters are not given. The development of a model to predict material behaviour before producing the castings would represent an additional predictive tool for material properties. In the present study, a model for the estimation of tensile as-cast properties of Al-Si-Mg castings was validated on a 22" wheel obtained by LPDC. Microstructural and mechanical properties were measured on the component both in as-cast and T6 condition. First, areas with different thicknesses and orientations were analysed and secondary dendrite arm spacing (SDAS) measurements were carried out. Subsequent tensile tests were performed on specimens from rim and spokes. Experimental data were used to verify the model results and to validate the as-cast model. Based on additional information provided by simulation and experimental data, a mathematical model to predict the mechanical properties after T6 heat treatment was developed.

KEYWORDS: ALUMINUM, HEAT TREATMENT, SIMULATION, MODEL, CASTING;

INTRODUCTION

A356 is an aluminum casting alloy widely used because of its good castability, corrosion resistance and mechanical properties, in particular high strength-to-weight ratio, which make it suitable for various applications in the automotive industry [1]. In order to allow its use in structural application, generally a T6 heat treatment is carried out to further increase the strength of the castings [2]. Nowadays the quality of castings is constantly improving, also thanks to casting simulation software that provide results in terms of microstructure, defects like shrinkage porosity, solidification time, fraction solid and residual stresses [3] by modelling both mold filling and solidification phenomena. For instance, Sadeghi et al. [4] used simulation to predict fluid flow and solidification steps of the castings while Aloe et al. [5] focused their attention on the development of numerical tools to successfully predict stresses, microstructures and defects. Commercial casting software are not able to provide mechanical

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strength values before and after heat treatment. However, the possibility to predict the material behavior would represent a precious tool for exploiting material properties and simplifying production processes.

The aim of the work is to develop a mathematical model to successfully predict the local mechanical strength of the casting from the main microstructural parameters. In particular, specific equations to predict yield strength and ultimate tensile strength for the as-cast and T6 conditions were studied using the commercial software ProCAST®. First, microstructural and mechanical properties were investigated on a 22" wheel obtained by LPDC process both in as-cast and T6 conditions. In parallel, using casting and geometrical parameters given by the foundry, a complete simulation was set up and a predictive model for as-cast condition was developed by exploiting the results. Experimental data were used for two main reasons: first, microstructural properties were used to verify the reliability of results from the casting simulation and then the validation of the predictive models for as-cast condition was carried out based on experimental tensile properties. Finally, a T6 model was proposed by extending the as-cast model previously validated.

EXPERIMENTAL PROCEDURE

The experimental tests were performed on two 22" wheels obtained by LPDC using A356 alloy, one in as-cast condition, the other one after T6 treatment. The T6 heat treatment performed by the foundry consisted of solution treatment at 530 °C, quenching and then aging at 146 °C for 3 hours. A preliminary analysis was carried out in different positions of the as-cast wheel in order to analyze the influence of geometry and cooling rate on microstructure and to identify relevant sections for further characterization.

Five samples from the main spoke (letter A) and three from the minor one (letter B) were taken from the as-cast component in order to investigate different thicknesses: A1 and B1 from the rim, A2 at the root of the spoke, A3, A4, B3, B4 from the spokes and A5 close to the hub (Fig. 1). Fewer samples were examined on the second spoke because after a preliminary analysis on the main one, it was

Tab.2 - Validation of as cast model.

	YSf [MPa]	YS [MPa]
	86.9	87.7 ± 2.1
	94.8	92.8 ± 1.9
	94.6	96 ± 1.4

A model for the as cast condition was also developed, but for the extension of the as cast model the coefficients were de-

termined following the same procedure as the as cast condition by exploiting experimental values of YS coming from tensile tests. The following equation is proposed:

$$YS = 125.6 - 1.67 \cdot L \cdot L \cdot (SDAS)$$

ULTIMATE TENSILE STRENGTH

After a study of literature the Ludwvig model represents the most reliable equation to predict UTS:

$$UTS = YS + K * \epsilon^\alpha$$

where K is a function of SDAStensile parameters. However, also casting conditions poro-

Tab.3 - Validation of as cast model.

	UTS finite element [MPa]	Experimental UTS [MPa]
A1	159.2	160.4 ± 7.3
A3	168.1	163.6 ± 6.1
B3	163.3	165.5 ± 5.9

CONCLUSIONS

In this study, a mathematical model to predict tensile behavior of A356 both for as-cast and T6 conditions as a function of microstructural parameters is proposed.

First, the yield strength was found to depend on SDAS and experimental values ensured the validation of the model for the as-cast condition. The same model was extended to predict the material behavior after heat treatment and new coefficients were found.

The ultimate tensile strength of the alloy was found to depend on SDAS, defects content and tensile parameters. After the validation of this model for the as-cast condi-

tions, a new predictive equation was developed also for T6 conditions by exploiting experimental values. The two equations result to be the same since the difference lies in the value of each variable involved.

The good results obtained suggest that the proposed models could be integrated in the casting simulation software to obtain the local distribution of mechanical properties to be used during the re-design step of a new component. In this way, a reduction of thicknesses, where possible, can be achieved, and the always more restricted criteria for the lightening of vehicles can be met.

REFERENCES

- [1] Kaufman J. G., Rooy E. L. Aluminium alloy castings, Properties, Processes and applications, ASM International; 2004.
- [2] Morri A. Correlations among microstructure, effect of thermal exposure and mechanical properties, in heat treated Al-Si-Mg and Al-Cu aluminium alloys. 2012; 1-2.
- [3] Abdullin A. D. New Capabilities of the ProCAST 2017 Software in Simulating Casting Processes. Metallurgist volume 61. 2017;433-438.
- [4] Ravi, B. Computer aided design and analysis for zero defects. International Conference on Aluminum. 2000; 1-6.
- [5] Aloe M., Lefebvre D., Mackenbrock A., Sholopurwalla A., Scott A. Advanced casting simulations. ESI Group, paper 30.
- [6] Chudasama B. J. Solidification Analysis and Optimization Using Pro-Cast. International Journal of Research in Modern Engineering and Emerging Technology, Vol. 1, Issue: 4. 2013
- [7] Shabani M. O., Mazaheri A. Prediction of Mechanical Properties of Cast A356 Alloy as a function of microstructure and cooling rate. Archives of Metallurgy and Materials, 2011; volume 56, issue 3.
- [8] Brusethaug S., Langsrud Y. Aluminum properties, a model for calculating mechanical properties in AlSiMgFe-foundry alloys. Metallurgical Science and Technology, Volume 18; 2000.