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

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A356 alloy is w[redacted]used to produce structural components by means of Low Pressure Die Casting (LPDC) process. Generally, a T[redacted]reatment (solution, quenching and aging treatment) is carried out to improve the strength of the casting. Now[redacted]ftware simulation of casting processes and solidification phenomena is a common practice for designing so[redacted]onents even if mechanical strength values and their correlation with microstructure parameters are not given[redacted] the possibility to predict material behaviour before producing the castings would represent an additional pr[redacted] for exploiting material properties. In the present study, a model for the estimation of tensile as-cast prop[redacted] on casting simulation was validated on a 22'' wheel obtained by LPDC. Microstructural and mechanical p[redacted]re investigated on the component both in as-cast and T6 condition. First, areas with different thicknesses a[redacted]onditions were analysed and secondary dendrite arm spacing (SDAS) measurements were carried out. S[redacted]tensile tests were performed on specimens from rim and spokes. Experimental data were used to verify[redacted] of simulation results and to validate the as-cast model. Based on additional information provided by s[redacted]are and experimental data, a mathematical model to predict the mechanical properties after T6 heat tr[redacted]o proposed.

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

NTRODUCTION

A356 is an aluminum casti[redacted]idely used because of its good castability, corrosio[redacted]ance and mechanical properties, in particular high str[redacted]h-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

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[redacted]

experimental values showed that the mean error in the property predict[illegible]on was about 2% of the actual measured value. The valida[illegible]on of this model ensured the possibility to implement t[illegible] equation into the software in order to obtain reliable [illegible]es of YS in any position of the casting, characterized by different thicknesses and solidification conditions, without performing any tensile tests. The simplicity of the equation is positive for its use at industrial level.

Tab.2 - Validation of as cast model.

	YS f[illegible] he[illegible]de [MPa]	E[illegible]e i[illegible]e[illegible] a YS [MPa]
[illegible]	86.9	87.7 ± 2.1
[illegible]	94.8	92.8 ± 1.9
[illegible]	94.6	96 ± 1.4

A model for t[illegible]on of YS for T6 condition was also developed, b[illegible]AS values, as an extension of the as cast mode[illegible]validated. Coefficients were defined following the same procedure as the as cast condition by exploiting experimental values of YS coming from tensile tests. The following equation is proposed:

$$YS = 135.6 + 1.67 * ln\,ln\,(SDAS) \quad (3)$$

ULTIMATE TE[illegible]TH MODEL

After a study of [illegible] was found that Ludwig model represents the most reliable equation to predict UTS:

$$UTS = YS + K * \varepsilon^{\alpha} \quad (4)$$

where K is a function [illegible]e ε depends on tensile parameters. However, al[illegible]efects, such as porosity level, are known to affe[illegible] strength, while they are not considered in Ludwig [illegible] As expecting, after analyzing the correlation between t[illegible]vel of casting defects given by the software and UTS values, it was found that the higher the shrinkage porosity, the lower the mechanical strength value. Therefore, also the level of shrinkage porosities was taken into account for a more accurate estimation of UTS values. The possibility to analyze the strength reduction due to casting defects would represent an additional precious tool for predicting how solidification phenomena can affect material properties. The level of casting defects, together with the other input variables of equation, came from simulation results. A model to predict UTS both for as-cast and T6 conditions was developed:

$$UTS = YS * (1 - 0.5 * \%SHR\_POROSITY) + \left(280 * 3 * e^{\frac{3.5}{SDAS}}\right) * \left(ln\,ln\left(1 + \frac{El\%}{100}\right)\right)^{0.5} \quad (5)$$

It is revealed that predictions from Eq. 5 are consistent with the experimental measurements of this property, thus the validation of the as-cast model is achieved (Tab. 3). In fact, the maximum error between the predicted UTS values and the experimental ones was about 5 MPa, which is lower than the experimental standard deviation. Thus, the validity of this metallurgical model is demonstrated.

In this study, the most innovative contribution lies in the development of a new predictive model characterized by the appearance of shrinkage porosity. T6 model was developed by extending the as-cast model previously validated and by exploiting experimental results coming from tensile tests.

Tab.3 - Validation of as cast model.

	UTS from the model [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 conditions, 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.

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