

Method for development of fast models predicting the mechanical properties of precipitation-hardenable aluminium alloys

A. Toenjes^{1*}, A. von Hehl^{1,2}

¹ IWT Stiftung Institut für Werkstofftechnik, Bremen, Germany;

² MAPEX Center for Materials and Processes, Bremen, Germany;

^{1,2} University of Bremen, Bremen, Germany.

*Corresponding author email: toenjes@iwt-bremen.de

Most heat treatment simulations of precipitation hardenable aluminium alloys are incomplete or restricted to sub-steps of the process chain. In general, literature addressing the heat treatment of aluminium components only provides a qualitative guidance of heat treatment that doesn't match with the heat treatment being necessary for specific parts with specific requirements. Thus, a quick and accurate simulation comprising the whole heat treatment process provides a great economical benefit for industrial application to predict suitable heat treatment processes meeting the required mechanical properties of inquired novel aluminium components. In this paper, the development of a time and cost efficient method to generate such prediction models is presented by means of the example aluminium alloy EN AW-6082. Comprising the process sub-steps of solution annealing, quenching and aging, time-temperature relations connected to the precipitation-hardening conditions were analysed. The precision of the prediction model depends on the size of the material data base that shall be able to be adjusted to the individual requirements of the simulation user. In order to keep the time and cost effort as low as possible to generate such a model a specific experimental design was developed. The results of the method development are presented and discussed.

Key Words – heat treatment, method development, D-optimal experimental design.

I. INTRODUCTION

In the production of aluminium components from heat-treatable alloys, precipitation hardening represents a major process step to the final adjustment and improvement of the mechanical properties. In general it's subdivided into the "solution annealing", "quenching" and "aging".

The microstructure development of the structure during the precipitation hardening forms the basis for the changes in mechanical properties. The parameters of the strength-enhancing phases such

as size, number and/or distribution are often used as input variables for the prediction of the firmness irrespective of whether they are experimental or simulative origin. In many cases, the basic equations of solid solution strengthening and precipitation hardening are used to calculate the yield and tensile strength and hardness [1, 2, 3, 4, 5].

In the industrial settings, an "ideal" heat treatment of aluminium components, as described in the literature for the most part, is often difficult to implement. Among other things, these difficulties are due to the diverse differences between industrial circumstances and laboratory conditions. This publication describes a method by which a model for predicting the mechanical properties of heat-treatable aluminium alloys can be produced with low experimental effort. In addition to sufficient calculation accuracy, the rapidity of the model is of paramount importance, as the model should fulfill the requirements for an online process simulation.

II. MATERIALS AND METHODS

The method was developed of the example aluminium alloy EN AW-6082. The chemical composition of the aluminium alloy was measured by glow discharge optical emission spectroscopy (GDOES). The results are presented in table 1.

Table 1 Chemical compositions of the samples

Element	Si	Mg	Mn	Fe	Cu	Others
Weight %	0.916	0.727	0.437	0.381	0.086	<0,05

Design of Experiments and Data Analysis was done using Cornerstone software. The variation of heat treatment parameters was done according the D-Optimal experimental design. Solution annealing temperature and times as well as quenching medium and aging

temperature and duration were varied. The heat treatment parameters are gathered in table 2.

Table 2 Heat treatment parameters

Solution temperature (°C)	500	530	560
Solution Time (h)	0,25	2,13	4
Method of cooling	Water	Gas	Polymer
Aging temperature (°C)	100	170	240
Aging Time (h)	2	11	20

After heat treatment hardness and electrical conductivity were measured and the tensile tests were carried out.

III. RESULTS AND DISCUSSION

By using the D-optimal experimental design, a wide spectrum of heat treatment conditions could be investigated with a low experimental effort. From the evaluation of the measured data the influence of the main factors resulted as well as the interactions of the influencing variables. As a result, the greatest impact on the hardness and the tensile strength of is the solution annealing temperature and the interaction between the aging temperature and time. The solution annealing time and quenching medium have only a small effect on these two mechanical properties (Fig. 1).

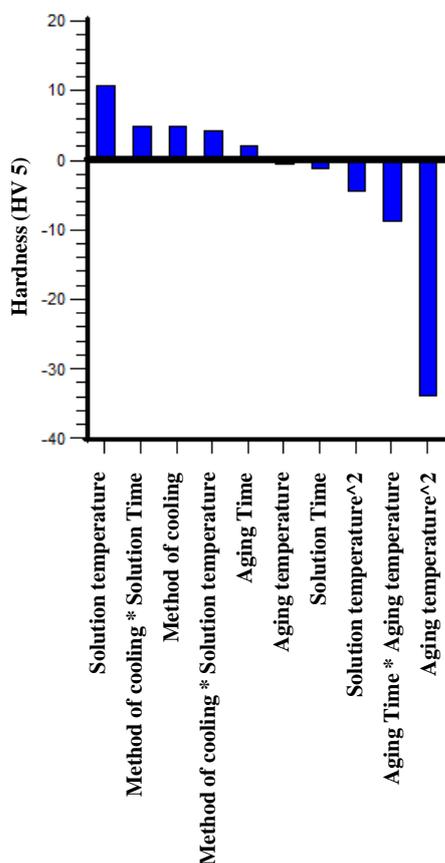


Figure 1. Effects Pareto for Hardness

In contrast to that, the electrical conductivity depends mainly on the solution annealing and aging temperature and the quenching medium.

IV. CONCLUSION

The developed method is suitable for rapid determination of the properties of heat-treatable aluminium alloys, where the experimental effort is significantly reduced by using the D-optimal experimental design. The accuracy of the results depends on the selected range of the heat treatment parameters. In the case, which the minimum quantity of data has been determined, the mechanical properties of various heat treatment conditions can be converted into one another.

ACKNOWLEDGEMENTS

The IGF Project (18641 N) of the Arbeitsgemeinschaft Wärmebehandlung und Werkstofftechnik e. V. (AWT) was funded by the Arbeitsgemeinschaft industrieller Forschungsvereinigungen „Otto von Guericke“ e. V. (AiF) through the IGF program of the Bundesministerium für Wirtschaft und Energie (BMWi) due to a resolution of the Deutscher Bundestag. The authors are grateful for the financial support.

We further wish to thank the Expert Committee 24 “Wärmebehandlung von Nichteisenmetallen” of AWT for scientific support and supervision of the project.

REFERENCES

1. Esmaeili, S., Lloyd, D. J., & Poole, W. J. (2003). *A yield strength model for the Al-Mg-Si-Cu alloy AA6111*. Acta Materialia 51, 2243 – 2257.
2. Esmaeili, S., & Lloyd, D. J. (2005). *Modeling of precipitation hardening in pre-aged AlMgSi(Cu) alloys*. Acta Materialia 53, 5257 – 5271.
3. Khan, I. N., Starink, M. J., & Yan, J. L. (2008). *A model for precipitation kinetics and strengthening in Al-Cu-Mg alloys*. Materials Science and Engineering A472, 66 – 74.
4. Sepehrband, P., & Esmaeili, S. (2008). *Application of recently developed approaches to microstructural characterization and yield strength modeling of aluminum alloy AA7030*. Materials Science and Engineering A487, 309 – 315.
5. Zander, J., & Sandström, R. (2008). *One parameter model for strength properties of hardenable aluminium alloys*. Materials and Design 29, 1540 – 1548.