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ON THE INFLUENCE OF HUMAN FACTOR ON MECHANICAL PROPERTIES IN ALUMINIUM HOT EXTRUSION PROCESS

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A non-parametric model was proposed for modelling the influence of different technological and chemical parameters on the mechanical properties of the 6082 aluminium alloys during the hot extrusion process with a special consideration of human factor. It was shown that human factor (influence of process engineers) was important and that it could be efficiently modelled and taken into account by the proposed Conditional Average Estimator (CAE) method. Production might be improved (optimized) by a proper education and/or by eliminating critical process engineers. It was found that the highest values for elongation and yield stress did not coincide with the range of the most frequent combinations of input parameters.

Key words: hot deformation, neural network, human factor, AA6082 alloy, CAE method

O utjecaju ljudskog faktora na mehanička svojstva u istiskivanju aluminija na toplo. Predložen je neparametarski model za modeliranje utjecaja različitih tehnoloških i kemijskih parametara na mehanička svojstva aluminijske legure 6082 tijekom istiskivanja na toplo s posebnim razmatranjem na ljudskom faktorom. Pokazano je, da je ljudski faktor (utjecaj proces inženjera) važan i da se može efikasno uzeti u obzir s predloženom CAE metodom. Proizvodnja se može poboljšati (optimirati) uz odgovarajuće obrazovanje i/ili uklanjanje kritičnih proces inženjera. Zapaženo je, da se najviše vrijednosti produljenja i naprezanja tečenja ne podudaraju s područjem najčešćih kombinacija ulaznih parametara.

Ključne riječi: deformacija na toplo, neuralne mreže, ljudski faktor, legura AA6082, CAE metoda

INTRODUCTION

It is well known that various parameters influence the mechanical properties of aluminium alloys (i.e. elongation, yield stress, tensile strength) [1, 2]. Next to chemical composition that is widely recognized to be the most influential parameter [1, 3], also other process parameters, i.e. casting temperature, casting rate, homogenization, extrusion ratio, ram speed, temperature in different phases of melt preparation, etc. as well as human factor influence the scatter of obtained mechanical properties of final product. Various influences of process parameters (i.e. geometry of extruded section) [4, 5] on mechanical properties were examined using simple statistical methods [6]. The majority of examinations deal with the comparison of different parameters in one process [6-11], but the analysis taking into account the entire process course are very rare in the available references [12]. The latter usually exhibit complex relationships between parameters and final properties of aluminium alloys. Especially the human factor has not been examined so far as an equal part to the other technological parameters and chemical composition. But it is well known from experiences that human factor may have a large influence on properties of the final product.

Therefore analysis of mutual influence of several input parameters, including human factor, on mechanical properties of extruded sections of the AA6082 alloy has been presented in this paper. Thus the CAE method that could be treated as a special type of probabilistic neural network [13, 14] was employed.

CAE METHOD AS A MATHEMATICAL TOOL FOR MODELLING MATERIAL PROPERTIES

Detailed description of the CAE method from the engineering point of view is given in Peruš et al. (2006) [15]. For better understanding and further explanations, the basic equations for determining any mechanical quantity in the hot extrusion process, i.e. yield stress, are repeated here:

$$\hat{q} = \sum_{n=1}^{N} q_n A_n, \quad A_n = \frac{a_n}{\sum_{i=1}^{N} a_i} \quad \text{and}$$

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$$a_n = \frac{1}{(2\pi)^{D/2} w^D} \exp\left[-\sum_{i=1}^{D} \frac{(b_1 - b_{nl})^2}{2w^2} \right] \quad (1)$$

In the above equations $\hat{q}$ is an estimate of yield stress, q_n is the same output variable related to the n-th model vector in the database, N is the number of model vectors in the database, b_{nl} is the l-th input variable of the n-th model vector in the database, and b_l is the l-th input variable related to the prediction vector. The model vector is defined on the basis of industrial measurements. D is the number of input variables that define the dimension of the sample space. Note that equation for a_n requires the input parameters to be normalized, generally in the range between 0 and 1, if the same width w of the Gaussian function for all the input variables is to be used. An intermediate result in the computational process is essential in modelling the influence of human factor in the presented study. This intermediate result is given by the parameter $\hat{\rho}$ that represents a measure of how the influence of all the model vectors in the database is spread over the sample space. It is strongly dependant on the smoothing parameter w and is defined as:

$$\hat{\rho} = \frac{1}{N} \sum_{n=1}^{N} a_n \quad (2)$$

It is used for detection of possible less accurate predictions (indicated by small values of $\hat{\rho}$) due to the data distribution in the database and due to local extrapolations outside the data range. Moreover, in case of human factor, it helps to detect the most frequent range of parameters of the hot extrusion process used by process engineers.

The average prediction error E_1 for yield stress that detects the quality of the prediction is determined as:

$$E_1 = \frac{1}{\bar{q}} \sqrt{\frac{1}{N} \sum_{n=1}^{N} (\hat{q}_n - q_n)^2} \quad (3)$$

where $\bar{q}$ is the mean experimental yield stress, and $\hat{q}_n$ and q_n are the n-th estimated and the experimental yield stress, respectively.

INDUSTRIAL DATABASE AND INPUT/OUTPUT PARAMETERS

Six different industrial databases that describe the entire course of the hot extrusion process of the 6082 alloys were created by the process engineers during one-year period. They include data on mechanical and casting parameters, parameters of homogenization, technological and analytical parameters during the extrusion process, and the quality and quantity of scrap material. For each extruded section 84 different parameters were measured. Based on the work order for the final product that was the key parameter of all the six databases, an effective database that was used in this study was created. Due to human errors during the data input only data for 3969 sections were usable (approx. 6 %) of all the initial data of 65 536 extruded sections. Other data were either missing or were not correctly put in.

In order to demonstrate the influence of human factor only few input parameters were selected. As already mentioned, the chemical composition had however the greatest influence on final properties. Only six chemical elements (Fe, Si, Mn, Mg, Cu, and Cr) that characterise the 6082 alloy next to the aluminium content were considered as input parameters. The extrusion ratio and ram speed were less influential, but nevertheless important. Human factor was taken into account as the influence of process engineers, indicated by discrete values as components of model vectors.

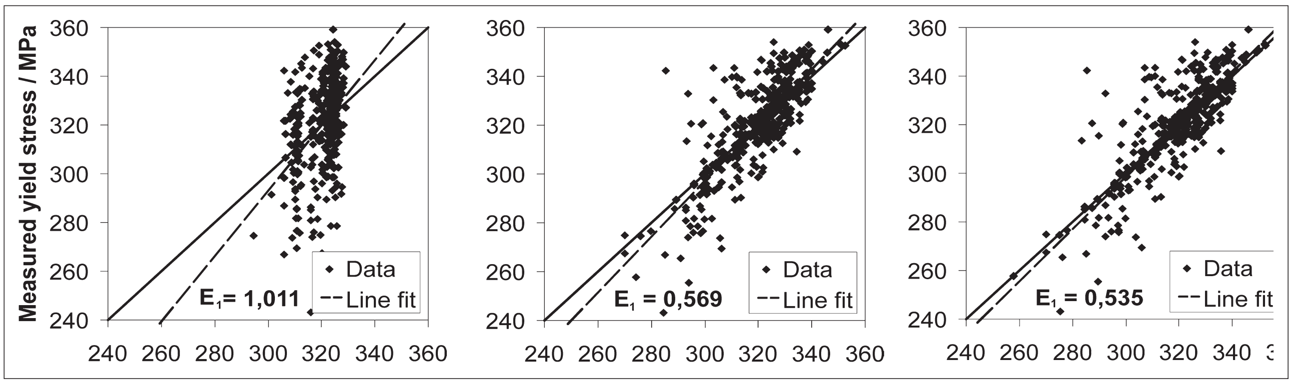
Two output parameters were selected as a representation of mechanical properties of the 6082 alloy, i.e. elongation and yield stress. Since there was a strong correlation between the yield stress and the tensile strength, only yield stress was thus chosen as an output parameter.

RESULTS AND DISCUSSION

Influence of different parameters on the mechanical properties of the 6082 alloys was indicated by the term E_1 (Eq. (3)), described in the previous section. Figure 1 shows the comparison between the predicted and the experimental values for yield stress. It was evident that the relation between the extrusion ratio plus ram speed, when taking into account the influence of process engineers, and the yield stress was poor (Figure 1.a) whereas the corresponding average prediction error E_l was large. When the influence of chemical composition was taken into account instead of the influence of process engineers, a much better relation was obtained (Figure l.b) and the average prediction error E_1 was reduced. Finally, when all the input parameters were taken into account (Figure l.c), prediction improved and the error E_1 was further reduced. The same observation could be noticed also for the linear fit that approached the line *predicted value = measured value* which defined the exact prediction.

The difference between the Figures. 1.b and 1.c was attributed to the influence of process engineers. It amounted 6 % in terms of the average prediction error E_1. The influence of process engineers was much smaller than that of chemical composition which amounted approximately 35 % and 43 % for the elongation and the yield stress, respectively. Nevertheless, the results showed that influence of process engineers could not be neglected.

In order to assess the influence of process engineers quantitatively, the yield stresses as a function of ram speeds and extrusion ratios were analysed. Figs. 2 and 3 present a comparison of the results obtained by the CAE method for one »highly efficient« (Figures 2.b and 3.b) and for one »less efficient« (Figures 2.c and 3.c) process engineer as well as the results where influence of pro-

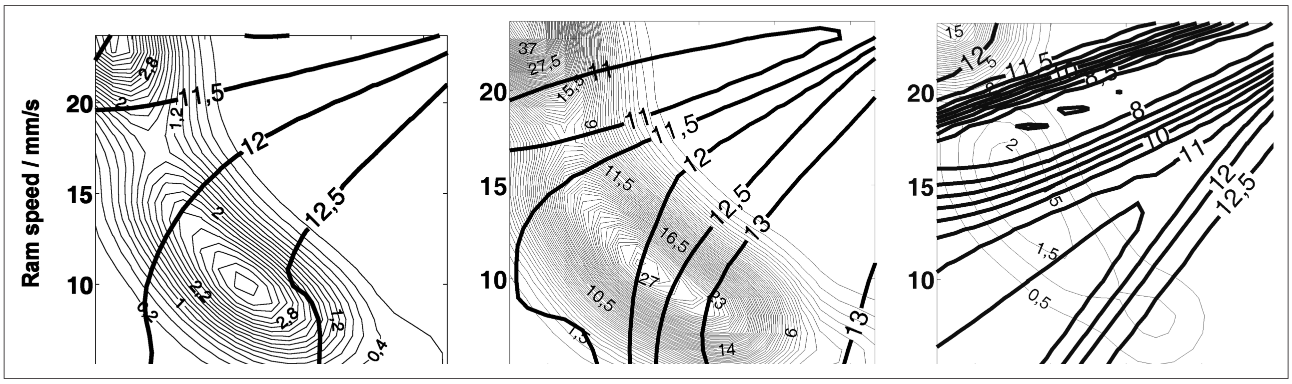


(a) extrusion ratio + ram speed + process engineers

(b) extrusion ratio + ram speed + chemical composition

(c) extrusion ratio + ram speed + chemical composition + process eng

Figure 1. Influence of different groups of parameters on the yield stress (w_n=0,1). Diagonal black line indicates exact prediction while dashed line indicates linear fit.

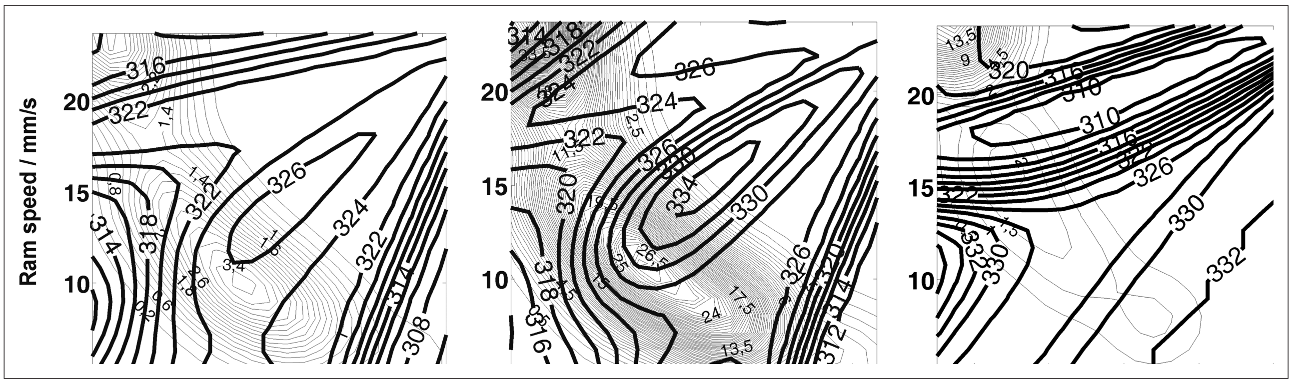


(a) process engineers excluded

(b) "highly efficient" process eng.

(c) "less efficient" process eng.

Figure 2. Influence of ram speed and extrusion ratio on the elongation represented by lines of equal values. The $\hat{\rho}$ equal-value lines are also indicated (thin lines).



(a) process engineers excluded

(b) "highly efficient" process eng.

(c) "less efficient" process eng.

Figure 3. Influence of ram speed and extrusion ratio on the yield stress represented by lines of equal values. The $\hat{\rho}$ equal-value lines are also indicated (thin lines).

cess engineers was excluded (Figures 2.a and 3.a) (only ram speed and extrusion ratio were taken into account).

The results are presented with the equal-value lines that represent constant values of the predicted elongation and the yield stress (Figures 2 and 3). As additional information, equal-value lines of the $\hat{\rho}$ -values (Eq. (2)) that are related to the reliability of predictions have been plotted as thinner lines with smaller fonts. The larger was the $\hat{\rho}$ -value, the more reliable were the results, and vice versa. In addition, $\hat{\rho}$ -values indicated a range of parameters within which the major part of the hot extrusion process took place.

Figures 2.a and 3.a show that optimal (i.e. highest) values for elongation and yield stress were not obtained with the same values of ram speed and extrusion ratio. In general, larger elongation values could be obtained with medium values of extrusion ratio and lower ram speeds (approx. 18 and 5 to 15 mm/s, respectively), and higher yield stresses with medium values of extrusion ratio and ram speeds (approx. 15 and 15 mm/s, respectively). Note that thinner lines indicated two main areas of ram speeds and extrusion ratios: (a) low extrusion ratio and high ram speed, and (b) medium extrusion ratio and medium ram speed.

Figures 2.b and 3.b show the same functional relationships as presented in Figures 2.a and 3.a with the exception that the results for »highly efficient« process engineer are presented in Figures 2.b and 3.b while the results for »less efficient« process engineer are presented in Figures 2.c and 3.c. In general, the same trends could be observed for all the process engineers. Some differences could be found only in details and in the parameter's range (see the $\hat{\rho}$ equal-value lines in Figures 2.b and 3.b compared to Figures 2.c and 3.c). It could be noticed also that the results for »highly efficient« process engineer (Figures 2.b and 3.b) matched very well with the general influence shown in Figures 2.a and 3.a where human factor was excluded from the analysis. On the other hand, a »less efficient« process engineer (Figures 2.c and 3.c) achieved typically the best results for a different range of input parameters than a »highly efficient« one, and they were worse than those with the »highly efficient« process engineer. It was interesting that a »less efficient« process engineers worked less than the »highly efficient« one (see the $\hat{\rho}$ density of equal-value lines). Though not presented here, it had to be mentioned that some high yield stresses were obtained by one of the process engineers at a low extrusion ratio and a high ram speed, and high elongation values at a relatively low ram speed and medium extrusion ratio by another process engineer.

It is important to emphasize that the optimal (highest) values for elongation and yield stress did not coincide with the optimal $\hat{\rho}$ -values. There were two reasons for that: (1) the optimal values for elongation and yield stress could not be obtained with the same values of ram speed and extrusion ratio; (2) since the production process was not yet optimized, »trial and error« procedure was evident and shifted both peaks apart.

CONCLUSIONS

A non-parametric model was proposed for modelling the influence of different technological and chemical parameters on the mechanical properties of the 6082 alloys during the hot extrusion. Special consideration was given to the influence of human factor. It was found that human factor could be efficiently modelled and taken into account by the proposed CAE method. From the obtained results the following conclusions might be derived:

1. Human factor (influence of process engineers) is important and in general can not be neglected due to oscillation of mechanical properties and actual data collection.
2. The highest (»peak«) values for elongation and yield stress do not coincide with the »peaks« of the $\hat{\rho}$ values (the area of the most frequent combination of input parameters).
3. Lack of optimization is clearly recognized from the mutual shifts of both peaks.
4. The optimal values for elongation and yield stress can not be obtained with the same values of ram speed and extrusion ratio.

It was shown that production could be improved by proper education and/or by eliminating critical process engineers. Further research, if the industry would express such an interest, would be aimed to determine more accurately the influence of individual process engineers. Namely, some input parameters in the hot extrusion process are mutually interdependent and those relations can not be influenced by process engineers.

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Note: Responsible for English language is A. Paulin.