EXTRA MACHINABILITY QUALITY PREDICTION

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SUMMARY

The steels with extra machinability are made according to special technological process. It depends on several parameters, particularly on the steel chemical composition, whether the steel will meet the quality according to extra machinability. By special test it is established whether the steel has extra machinability or not. In our researches the prediction of extra machinability of steels, depending on input parameters, was performed by logistic regression and genetic programming. The research shows that genetic programming model performs better. The best model developed during the simulated evolution was practically verified.

Keywords: Steel quality, extra machinability, modeling, logistic regression, genetic programming

1. INTRODUCTION

In general, tool steels are divided into ordinary steels and steels with extra machinability. These two groups differ in the technology of steel manufacture, which influences the steel properties during machining processes (e. g. turning, milling). In case of steel with extra machinability it is possible to reach much higher resistance of cutting tools even with higher cutting speeds, therefore the price of such steels is 10 % higher on the average than the price of the ordinary steel [1].

The steels with improved machinability retain all good qualities of ordinary steels their advantage being that they allow machining at 25-50 % higher cutting speeds, 4-6 times lower tool wear and 30 % reduction of machining cost.

In case of steel with extra machinability the molten metal is treated with calcium, which improves their machining properties. Instead of aluminium oxides the steel with extra machinability contains calcium aluminates of 2-20 µm size which are of regular forms and uniformly scattered. In this steel the calcium aluminates have sulphide surface. The heat in the cutting zone softens the sulphide surface and ensures the cutting tool to have lubrication effect. As a result, the tool wear in lower and higher machining speeds are allowed.

The test of the steel machinability quality is preformed according to the technological standard ISO 3685 [2]. The test process is demanding and time-consuming. As long as the data on machinability are not known, the steel cannot be included in the further technological process. In the steel does not reach the degree of extra machinability it is considered to be ordinary steel. The steel machinability is influenced particularly by the chemical composition. As there are several chemical elements in the steel its machinability is hard anticipate and predict. In addition, also other technological parameters change, which additionally make the steel machinability prediction difficult.

In the paper prediction of steel machinability by logistic regression and genetic programming was used. The both methods were also compared. Prediction of machinability of steel helps to avoid time-consuming and expensive testing of steel machinability and to contribute to improvement of the material flow in the production process.

2. TEST OF TOOL RESISTANCE

Quality of extra machinability steel is verified by parameter v_{15} which is prescribed for each grade of steel.

The parameter v_{15} is the speed of cutting of the tool which is worn out within 15 minutes. The tool wear is prescribed. The test of tool resistance is preformed on a CNC lathe.

That test is carried out for each batch separately. The batch is the quantity of steel cast as a whole in the steelworks. The mass of one batch is 52 000 kg. Each batch is identified by its identification number. The steel sample for finding out the machinability must have the diameter of at least 60 mm and the minimum length of 500 mm. After machining (turning) without cooling, within time t (approximately fifteen minutes) and with selected speeds, the wear of the cutting insert is measured under a microscope (Figure 1). The tip of the insert (V_{BB}) may be worn out for not more then 0.30 mm and the entire insert edge ($V_{BB\,max}$) for not more than 0.60 mm. Afterwards, the parameter v_{15} is calculated by Taylor's equation [3]:

$$v \cdot t^n = C, \qquad (1)$$

where v is cutting speed, t is cutting time, n is constant depending on tool material.

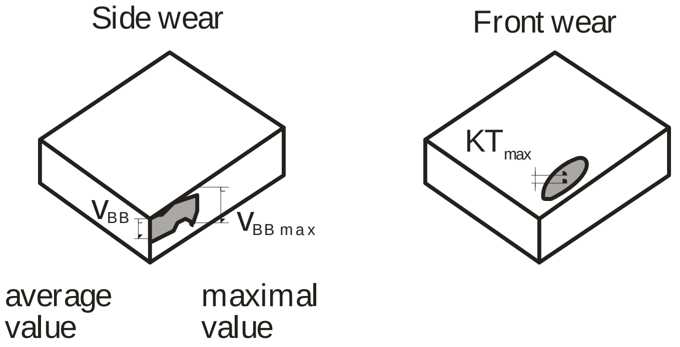

Figure 1. Side and front wear

3. EXPERIMENTAL BACKGROUND

The data were collected in the period of 13 months in the factory Štore Steel Ltd. from Slovenia. The most influencing parameters are the sample diameters and the chemical elements (calcium, oxygen and sulphur) necessary for production of steel with extra machinability. 140 batches were made. Out of them 125 were adequate. If the batch is adequate this means when parameter v_{15} in the individual batch exceeds the prescribed value v_{15} for that batch. The prescribed value of parameter v_{15} depends on the grade of steel. Consequently, during that period the success of production of steels was 21/146 = 85.61%. The number of each steel grade specimens and the average chemical composition is presented in Table 1.

Table 1. Steel grades and the average chemical composition

Steel grade	Number of specimens	%Ca	%O	%S
16MnCrS5	2	0.0305	0.034	0.0275
C45	139	0.0293	0.0462	0.0270
C50	2	0.0235	0.0145	0.021
C15	1	0.029	0.019	0.028
St70.2	2	0.03	0.0375	0.029
Sum:	146			

The experimental data and extra machinability suitability are presented in Table 2. If the batch of steel is adequate then it is marked with logical variable 1 and with 0, if it is not.

Table 2. Experimental data

#	Batch number	Steel grade	Sample diameter	%Ca	%O	%S	v_{15}	Prescribed v_{15}	Extra machinability
1	36968	C45	19.0	0.024	0.019	0.031	327	360	0
2	37101	16MnCrS5	60.0	0.026	0.044	0.027	453	410	1
3	37236	C50	70.0	0.026	0.005	0.022	308	360	0
4	37237	C50	70.0	0.021	0.024	0.02	346	360	0
…	…	…	…	…	…	…	…	…	…
143	37322	C45	70.0	0.027	0.018	0.025	261	250	1
144	37358	C45	70.0	0.033	0.042	0.028	452	450	1
145	37359	C45	70.0	0.029	0.044	0.022	459	450	1
146	37360	C45	68.0	0.033	0.046	0.025	438	410	1

4. EXTRA MACHINABILITY MODELING

Evaluation of models were determined by Bayesian analysis (true positive *TP*, true negative *TN*, false positive *FP*, false negative *FN*) applying sensitivity *SENS*=*TP*/(*TP*+*FN*), specificity *SPEC*=*TN*/(*FP*+*TN*), positive predictive value *PPV*=*TP*/(*TP*+*FP*) and negative predictive value *NPV*=*TN*/(*FN*+*TN*).

The parameters in the mathematical models for extra machinability are denoted as:
- *FI* - sample diameter,
- *Ca* - weight percent of calcium,
- *O* - weight percent of oxygen and
- *S* - weight percent of sulphur.

4.1. Logistic regression modeling

The most important results of logistic regression are presented in Table 3.

Table 3. Logistic regression results

Parameter	*B*	S.E.	Wald	*df*	Sig.	exp(*B*)
FI	0.058	0.032	3.278	1	0.070	1.060
Ca	123.607	67.251	3.378	1	0.066	4.805
O	101.616	27.171	13.986	1	0.000	1.353
S	326.759	131.147	6.208	1	0.013	8.123
Constant	-18.537	5.089	13.268	1	0.000	0.000

According to the logistic regression results the logistic mathematical model for extra machinability is:

$$\log\left(\frac{p}{1-p}\right) = 0.058 \cdot FI + 123.607 \cdot Ca + 101.616 \cdot O + 326.759 \cdot S - 18.537 \quad , \qquad (2)$$

where $\underline{p}$ is the probability of steel not being extra machinability steel. If the probability p was lower then 0.5, then the extra machinability was denoted as 1 otherwise as 0.

The logistic regression model sensibility is 0.976, specificity 0.524, positive predictive value 0.924, negative predictive value 0.786 and test efficiency 0.911.

4.2. Genetic programming modeling

Genetic programming is probably the most general evolutionary optimization method [4-6]. The organisms that undergo adaptation are in fact mathematical expressions (models) for extra machinability prediction consisting of the available function genes (i.e., basic arithmetical functions) and terminal genes (i.e., independent input parameters, and random floating-point constants). In our case the models consist of: function genes of addition (+), subtraction (-), multiplication (*) and division (/), terminal genes of sample diameter (*FI*) and chemical composition of steel (*Ca*, *O* and *S*).

Random computer programs of various forms and lengths are generated by means of selected genes at the beginning of simulated evolution. Afterwards, the varying of computer programs during several iterations, known as generations, by means of genetic operations is performed. After completion of varying of computer programs a new generation is obtained that is evaluated and compared with the experimental data, too.

The result values of models for extra machinability prediction above zero predicted that the steel is extra machinability steel (value 1), otherwise not (value 0).

The process of changing and evaluating of organisms is repeated until the termination criterion of the process is fulfilled. This was the prescribed maximum number of generations.

For the process of simulated evolutions the following evolutionary parameters were selected: size of population of organisms 500, the greatest number of generation 100, reproduction probability 0.4, crossover probability 0.6, the greatest permissible depth in creation of population 6, the greatest permissible depth after the operation of crossover of two organisms 10 and the smallest permissible depth of organisms in generating new organisms 2. Genetic operations of reproduction and crossover were used. For selection of organisms the tournament method with tournament size 7 was used.

We have developed 100 independent civilizations of mathematical models for prediction of extra machinability. Only one out of 100 is presented here:

$$\begin{aligned}&2O-\frac{0.89395\cdot O}{\frac{1.70735}{O}+O+\frac{2.32712}{S}}+S--\frac{0.89395\left(O-\frac{0.89395O}{\frac{-1.70735}{O}+\frac{1.16356}{S}}+S\right)}{O+\frac{O(CA+FI+S)-\frac{0.48069\left(-\frac{1.70735}{O}+O+\frac{2.32712}{O+S}\right)}{-2.32712+O}}{O-S}}-\\&-\frac{0.89395(O+S)}{O(CA+FI+3S)+\frac{2.32712}{-FI+O-S-\frac{2.32712}{-FI+O-S-\frac{1.11863\left(-\frac{1.70735}{O}+O+\frac{2.32712}{O+S}\right)}{O(2.32712+S)}}}},\end{aligned}\tag{3}$$

with sensibility of 1, specificity 0.810, positive predictive value 0.969, negative predictive value 1 and test efficiency 0.973.

5. CONCLUSIONS

Due to their specific properties if compared with ordinary steels, the steels with extra machinability will represent a growing share on the market. Their advantage over the remaining steels, in particular, is that they can be machined at higher machining speeds and that they assure smaller cutting tool wear.

In researches two approaches were used for predicting the steel machinability – logistic regression and genetic programming. Evaluation of models was determined by Bayesian analysis.

The logistic regression model was obtained with sensibility 0.976, specificity 0.524, positive predictive value 0.924, negative predictive value 0.786 and test efficiency 0.911.

The best genetic programming model (out of 100) performed better with sensibility of 1, specificity 0.810, positive predictive value 0.969, negative predictive value 1 and test efficiency 0.973. Out of 146 values the best model wrongly predicts 4 values; it means that its reliability is 97.26%. In case of all 4 wrong predictions the model predicts that the steel has appropriate machinability, while in fact it does not have it.

Research has shown that by using the genetic programming method for prediction of appropriateness of the steel machinability it is possible to establish efficient planning and optimizing of production, to reduce the costs of researches and the handling changes and, finally, to increase satisfaction of the buyers due to shorter delivery times. The future researches will be focused on testing the mathematical model and optimizing the chemical composition. The prognosis is optimistic.

6. REFERENCES

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