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Prediction of steel machinability by genetic programming

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Analysis and modelling

ABSTRACT

Purpose: This paper describes intelligent system to predict steel machinability.

Design/methodology/approach: The prediction of machinability of steel, depending on input parameters (percentage of calcium, percentage of oxygen, percentage of sulphur), was performed by means of genetic programming and data on the batches of steel already made.

Findings: The mathematical model to predict machinability of steel obtained by genetic programming method gives only 4 wrong predictions out of 146 experimental values. The model was tested also with testing data set. The machinability of the complete test batches (27 experimental values) was successfully predicted.

Research limitations/implications: Limitation of the proposed concept is the size of test data (N = 27), which means longer testing period. The 146 batches, which were used for modeling, were collected in the period of February 2004 to April 2005.

Practical implications: With the proposed approach, 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.

Originality/value: The paper presents new and innovative approach to predict steel machinability by genetic programming. The prediction precision is at high level. The results show that the proposed concept can be successfully used in practice.

Keywords: Analysis and modelling; Metallic alloys; Extra machinability; Evolutionary computation; 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 the 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 about 10% higher than the price of ordinary steel.

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

In steel with extra machinability, the molten metal is treated with calcium, which improves its machining properties. Instead of aluminium oxides the steel with extra machinability contains calcium aluminates of 2-20μm size which are of regular forms and uniformly scattered. In this steel the calcium aluminates have a 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 is preformed according to the technological standard ISO 3685. 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. If 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 to anticipate and to predict. In addition, also other technological parameters change, which additionally make the steel machinability prediction difficult.

The paper proposes prediction of steel machinability by the genetic programming (GP). The GP imitates the principles of biological evolution, such as genetic combining and natural selection. The GP was introduced by Koza in the 1990's [1-3] and is one of the most fast growing methods of evolutionary algorithms (also known as evolutionary computation [4]). A huge number of successful implementation of evolutionary algorithms has been reported so far (see for example [5-8]).

In the proposed concept, the mathematical models for prediction of steel machinability are subject to adaptation. 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.

Section 2 presents theoretical background and explains the test of the tool resistance. Section 3 discuses the experimental data which are basis for modeling the prediction of steel machinability. Modeling is performed in Section 4, where also the results are indicated. Section 5 gives conclusive findings.

2. Test of the tool resistance

Appropriateness of steel with extra machinability 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 performed on a CNC lathe.

The 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 50000kg. Each batch is identified by its identification number. The steel sample for finding out the machinability must have the diameter of at least 60mm and the minimum length of 500mm. After machining without cooling at the selected speed within time t (approximately 15 minutes), the wear of the cutting insert is measured under a microscope (Figure 1). The tip of the insert (V_{BB}) may be worn out less than 0.30mm and the entire insert edge ($V_{BB\ max}$) for less than 0.60mm. Afterwards, the parameter v_{15} is calculated [20].

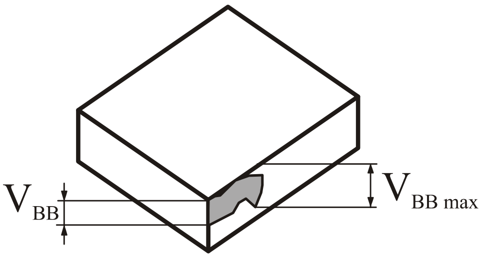

Fig. 1. Side wear

Generally, the tool resistance is calculated according to the Taylor's equation [21]:

$$v \cdot t^n = C \tag{1}$$

where v is cutting speed, t is cutting time, n is constant depending on tool material, and C is constant. For example, if the cutting speed is v = 330m/min and the time within which tool wear takes place is t = 22.6min, the parameter v_{15} is equal to 365.6m/min as shown below:

$$\begin{aligned} v \cdot t^n &= v_{15} \cdot 15^n \\ v \cdot t^{0.25} &= v_{15} \cdot 15^{0.25} \\ v_{15} &= v \cdot \frac{t^{0.25}}{15^{0.25}} \\ v_{15} &= 330 \cdot \frac{22.6^{0.25}}{15^{0.25}} = 365.6 \end{aligned} \tag{2}$$

3. Experimental background

To be able to develop mathematical models for prediction of machinability of steels by genetic programming, a set of measurements have to be preformed. Table 1 in Appendix shows the data for the individual batch. The data were collected in the period from February 2004 to April 2005 in the steelworks Store Steel Ltd. in Slovenia [22]. The most influencing parameters are the sample diameters and the chemical elements (calcium, oxygen and sulphur) necessary for production of steel with extra machinability. Out of 146 batches 125 were adequate. If the batch is adequate, it means that the steel has extra machinability. Consequently, during that period the success of production of steels was 85.61%. Table 1 shows that 18 different grades of steel are concerned. The steel with extra machinability is adequate, when parameter v_{15} in the individual batch exceeds the required value v_{15} for that batch. The required value of parameter v_{15} depends on the steel grade. Production and/or individual batch of steel having adequate grade is marked with logical variable 1, and with 0, if it does not have one.

4. Modelling

4.1. Preparatory stage

Before GP modeling it is necessary to select suitable terminal and function genes from which the evolutionary process will try to build as fit an organism (i.e. mathematical model) as possible for machinability prediction. The organisms have the nature of computer programs differing in form and size. Organisms consist of terminal and function genes [1,2].

In our case the set of terminal genes T is:

T = {FI, CA, O, S, R},

where FI is sample diameter, CA is percentage of calcium, O is percentage of oxygen, S is percentage of sulphur, and R are real numbers in the interval between -1 and 1.

The selected set of function genes *F* is:

$F = \{+, -, *, \%\}$,

where + is mathematical operation of addition, − is mathematical operation of subtraction, * is mathematical operation of multiplication, and % is mathematical operation of division protected against extreme values (detail description of protection mechanism can be found in [1,2]).

Let us assume as follows. If the organism (i.e. mathematical model) returns the value smaller than or equal to 0, then the steel with such properties does not have extra machinability and logical value 0 is prescribed to the steel; if the organism returns the value greater than 0 then the steel with such properties has extra machinability and logical value 1 is prescribed to the steel.

The quality of the individual organism (i.e. prediction) is found out using fitness function. In our case a relatively simple function is concerned, since it is necessary to find out only the share of correct prediction (i.e. to count the number of predictions matching the experimental result in Table 1). The greater the share, the better the prediction model.

4.2. Evolutionary parameters and evolutionary flow

Genetic operations of reproduction (selection), crossover, and mutation were used. The following evolutionary parameters were selected: population size 500, the maximum number of generation 100, probability of reproduction 0.2, probability of crossover 0.7, probability of mutation 0.1, 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 initial generation 2. For selection of organisms the tournament approach with tournament size of 7 was used [2].

Evolutionary searching for solutions starts with random generating 500 computer programs consisting of terminal genes *T* and function genes *F*. In the next step the organisms are evaluated using fitness function described above and the training data set in Table 1. After evaluation the organisms are changed by genetic operators. Varying and evaluation of population are repeated until the termination condition has been fulfilled. In our case we specified that evolution may take place up to the prescribed maximum number of generations.

4.3. Results

One hundred independent civilizations of mathematical models for prediction of steel machinability appropriateness have been developed. To make the presentation more clear let us have a look at the development of one of the independent civilizations.

The result of the blind random searching for mathematical models in the initial generation is bad. The best mathematical model for prediction of steel machinability appropriateness in generation 0 is:

$$O\cdot FI-1.9491\,. \tag{3}$$

The above model gives 15 incorrect predictions out of 146 batches. Thus, the reliability of such model is 89.73%.

In addition to fit organisms in the initial generation there are also less fit individuals. The most unfit organism in generation 0 is equal to the expression

$$O+S+2.3425, \tag{4}$$

which gives 19 incorrect predictions of the steel machinability. It means that the model reliability is 86.99%. It is interesting that in initial generation there is no significant difference between the fit and the most unfit organism.

In generation 50, the organisms are more highly developed and adapted to the environment (experimental data). The fittest organism in generation 50 is:

$$\begin{aligned}&2FI-\frac{9.22233+CA+O}{O}-\\&-(2.72604+2CA+O)\left(CA-FI+\frac{CA}{-1.9491+FI\cdot O}\right)+2S\end{aligned} \tag{5}$$

with 93.15% reliability.

In generation 87, the evolution developed the fittest organism of the civilization. It is equal to the expression:

$$\begin{aligned}&2O-\frac{0.89395\cdot O}{\frac{1.70735}{O}+O+\frac{2.32712}{S}}+S-\\&-\frac{0.89395\left(O-\frac{0.89395O}{\frac{-1.70735}{O}+\frac{1.16356}{S}}+s\right)}{O+\frac{O(CA+FI+S)-\frac{0.48069\left(-\frac{1.70735}{O}+O+\frac{2.32712}{O+S}\right)}{-2.32712+O}}{O-S}}-\\&-\frac{0.89395(O+S)}{O(CA+FI+3S)+\frac{2.32712}{-FI+O-S-\frac{2.32712}{-FI+O-S-\frac{1.11863\left(-\frac{1.70735}{O}+O+\frac{2.32712}{O+S}\right)}{O(2.32712+S)}}}}\end{aligned} \tag{6}$$

Model (6) gives only 4 wrong predictions, consequently its reliability is 97.26%. It can be expected that on the average out of 100 predictions the model will predict thrice the logical variables 0 or 1 which will not correspond to the actual condition.

4.4. Testing of the model

Testing of the fittest model (6) was performed on the basis of 27 batches made during the period from April 2005 to May 2005. Experimental data for testing are collected in Table 2 in Appendix.

Table 1.
Experimental data (training data set)

#	Batch number	Grade	FI [mm]	Ca[%]	O[%]	S[%]	v_{15}	v_{15} required	Adeq.
1.	36968	C 45	90.0	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	C 50	70.0	0.026	0.005	0.022	308	360	0
4.	37237	C 50	70.0	0.021	0.024	0.02	346	360	0
5.	37260	16MnCrS5	80.0	0.035	0.024	0.028	444	410	1
6.	37261	C 15	85.0	0.029	0.019	0.028	482	450	1
7.	37262	C 45	90.0	0.024	0.019	0.022	341	360	0
8.	37284	C 45	70.0	0.02	0.015	0.023	298	360	0
9.	37285	C 45	70.0	0.024	0.026	0.023	304	360	0
10.	37321	St 52.3	70.0	0.035	0.034	0.023	462	450	1
11.	37322	482	70.0	0.027	0.018	0.025	261	250	1
12.	37358	St 52.3	70.0	0.033	0.042	0.028	452	450	1
13.	37359	Rst 37.2	70.0	0.029	0.044	0.022	459	450	1
14.	37360	16MnCrS5	68.0	0.033	0.046	0.025	438	410	1
15.	37361	C 45	70.0	0.028	0.023	0.028	357	360	0
16.	37411	C 45	70.0	0.035	0	0.03	360	360	1
17.	37432	C 45	73.0	0.03	0.045	0.029	360	360	1
18.	37488	16MnCrS5	73.0	0.038	0.061	0.031	453	410	1
19.	37489	St 70.2	83.0	0.035	0.036	0.024	390	360	1
20.	37490	C 45	83.0	0.03	0.048	0.029	406	360	1
21.	37529	16MnCrS5	70.0	0.024	0.059	0.035	442	410	1
22.	37530	16MnCrS5	63.0	0.025	0.065	0.033	413	410	1
23.	37531	St 52.3	63.0	0.026	0.041	0.028	437	450	0
24.	37532	Rst 37.2	70.0	0.036	0.053	0.028	484	450	1
25.	37533	C 45	70.0	0.035	0.092	0.028	411	360	1
26.	37592	C 45	70.0	0.024	0.035	0.026	390	360	1
27.	37622	C 45	80.0	0.035	0.044	0.031	399	360	1
28.	37706	16MnCrS5	70.0	0.035	0.053	0.026	430	410	1
29.	37707	482 B	70.0	0.022	0.032	0.026	268	250	1
30.	37726	16MnCrS5	95.0	0.032	0.055	0.025	453	410	1
31.	37727	C 45	95.0	0.03	0.058	0.026	386	360	1
32.	37745	16MnCrS5	100.0	0.026	0.064	0.027	443	410	1
33.	37746	TSTE 460	95.0	0.034	0.061	0.025	456	450	1
34.	37747	TSTE 460	95.0	0.03	0.058	0.022	456	450	1
35.	37748	St 70.2	110.0	0.027	0.057	0.027	373	360	1
36.	37749	C 45	80.0	0.026	0.052	0.026	399	360	1
37.	37775	16MnCrS5	70.0	0.028	0.059	0.027	453	410	1
38.	37776	16MnCrS5	70.0	0.027	0.049	0.024	453	410	1
39.	37777	16MnCrS5	70.0	0.031	0.06	0.026	438	410	1
40.	37779	St 52.3	70.0	0.03	0.026	0.02	422	450	0
41.	37780	C 45	70.0	0.026	0.061	0.026	411	360	1
42.	37871	C 45	70.0	0.02	0.034	0.025	322	360	0
43.	37872	C 45	70.0	0.023	0.023	0.025	245	360	0
44.	37938	C 45	70.0	0.026	0.024	0.025	338	360	0
45.	37989	21MnCr5	70.0	0.024	0.04	0.025	445	400	1
46.	37990	C 45	70.0	0.031	0.039	0.025	411	360	1
47.	37991	482 B	70.0	0.026	0.036	0.027	266	250	1
48.	38025	16MnCrS5	70.0	0.028	0.061	0.025	466	410	1
49.	38026	16MnCrS5	70.0	0.03	0.039	0.028	460	410	1
50.	38027	Rst 37.2	70.0	0.025	0.038	0.027	474	450	1
51.	38028	16MnCrS5	68.0	0.026	0.037	0.03	438	410	1
52.	38055	C 45	70.0	0.029	0.046	0.024	411	360	1
53.	38056	C 45	70.0	0.028	0.04	0.027	417	360	1
54.	38104	C 45	70.0	0.034	0.056	0.026	405	360	1
55.	38111	C 45	70.0	0.022	0.07	0.027	405	360	1
56.	38126	St 70.2	83.0	0.033	0.042	0.025	392	360	1
57.	38127	St 70.2	83.0	0.023	0.051	0.025	411	360	1
58.	38128	C 45	83.0	0.022	0.046	0.026	392	360	1
59.	38129	C 45	70.0	0.032	0.045	0.025	311	360	0

60.	38130	C 50	70.0	0.034	0.051	0.022	397	360	1
61.	38191	16MnCrS5	70.0	0.034	0.053	0.03	448	410	1
62.	38230	482 B	90.0	0.037	0.022	0.03	259	250	1
63.	38232	St 52.3	90.0	0.035	0.069	0.027	473	450	1
64.	38233	16MnCrS5	65.0	0.033	0.047	0.025	410	410	1
65.	38285	16MnCrS5	70.0	0.026	0.075	0.031	453	410	1
66.	38286	C 45	70.0	0.035	0.048	0.024	397	360	1
67.	38287	C 45	70.0	0.035	0.049	0.026	397	360	1
68.	38288	C 45	83.0	0.031	0.047	0.027	399	360	1
69.	38346	16MnCrS5	70.0	0.031	0.057	0.026	410	410	1
70.	38347	20MnCrS5	68.0	0.025	0.045	0.025	410	410	1
71.	38348	16MnCrS5	70.0	0.026	0.068	0.026	438	410	1
72.	38382	16MnCrS5	70.0	0.023	0.055	0.03	453	410	1
73.	38390	St 52.3	100.0	0.024	0.04	0.028	470	450	1
74.	38391	16MnCrS5	100.0	0.027	0.067	0.026	438	410	1
75.	38392	C 45	105.0	0.032	0.053	0.031	373	360	1
76.	38450	C 45	90.0	0.026	0.022	0.026	360	360	1
77.	38451	C 45	90.0	0.035	0.046	0.025	394	360	1
78.	38452	C 45	90.0	0.013	0.034	0.027	377	360	1
79.	38453	C 45	90.0	0.03	0.033	0.034	370	360	1
80.	38468	C 45	90.0	0.035	0.047	0.026	377	360	1
81.	38469	C 45	90.0	0.034	0.04	0.025	370	360	1
82.	38470	C 45	90.0	0.03	0.038	0.021	341	360	0
83.	38471	C 45	90.0	0.033	0.038	0.025	386	360	1
84.	38472	C 45	90.0	0.034	0.046	0.026	370	360	1
85.	38529	C 45	90.0	0.021	0.045	0.022	377	360	1
86.	38531	C 45	90.0	0.035	0.067	0.025	401	360	1
87.	38532	C 45	90.0	0.031	0.045	0.023	386	360	1
88.	38549	482	70.0	0.035	0.048	0.029	278	250	1
89.	38559	16/20 MnCr5	80.0	0.02	0.035	0.03	478	410	1
90.	38571	16MnCrS5	75.0	0.033	0.053	0.027	459	410	1
91.	38572	Ck 45	75.0	0.034	0.057	0.027	402	360	1
92.	38573	42CrMoS4	75.0	0.032	0.051	0.028	241	210	1
93.	38593	St 70.2	83.0	0.03	0.061	0.032	417	360	1
94.	38597	16MnCrS5	73.0	0.023	0.043	0.028	438	410	1
95.	38598	21MnCr5	70.0	0.032	0.065	0.025	430	400	1
96.	38599	St 70.2	83.0	0.041	0.044	0.026	399	360	1
97.	38601	C 45	83.0	0.027	0.04	0.028	417	360	1
98.	38602	C 45	83.0	0.028	0.048	0.027	399	360	1
99.	38603	St 52.3	83.0	0.035	0.076	0.026	500	450	1
100.	38604	St 52.3	65.0	0.03	0.046	0.028	473	450	1
101.	38605	16MnCrS5	70.0	0.029	0.058	0.031	466	410	1
102.	38621	A 105	80.0	0.032	0.035	0.028	500	450	1
103.	38622	C 45	70.0	0.028	0.036	0.031	397	360	1
104.	38623	16MnCrS5	80.0	0.028	0.056	0.031	410	410	1
105.	38672	C 45	80.0	0.024	0.031	0.026	363	360	1
106.	38673	C 45	80.0	0.026	0.033	0.026	330	360	0
107.	38674	C 45	80.0	0.032	0.031	0.026	360	360	1
108.	38681	C 45	80.0	0.026	0.041	0.026	377	360	1
109.	38756	16MnCr5	80.0	0.03	0.058	0.022	460	410	1
110.	38757	16MnCr5	80.0	0.033	0.05	0.026	440	410	1
111.	38758	16MnCr5	65.0	0.028	0.045	0.027	430	410	1
112.	38759	C 45	80.0	0.032	0.031	0.024	390	360	1
113.	38760	16MnCr5	80.0	0.035	0.044	0.023	460	410	1
114.	38761	16MnCr5	80.0	0.029	0.041	0.028	460	410	1
115.	38762	16MnCr5	70.0	0.03	0.047	0.03	442	410	1
116.	38785	16MnCr5	68.0	0.026	0.043	0.028	442	410	1
117.	38810	C 45	70.0	0.034	0.041	0.029	397	360	1
118.	38811	C 45	70.0	0.028	0.028	0.023	322	360	0
119.	38844	St 70.2	110.0	0.024	0.032	0.027	383	360	1
120.	38893	C 45	70.0	0.028	0.048	0.026	388	360	1
121.	38894	482	70.0	0.027	0.039	0.029	278	250	1
122.	38895	482	70.0	0.03	0.041	0.028	278	250	1

123.	38933	20MnCrS5	70.0	0.025	0.042	0.025	397	400	0
124.	38934	C 45	70.0	0.027	0.029	0.029	314	360	0
125.	38935	St 52.3	70.0	0.029	0.045	0.026	438	450	0
126.	38936	16MnCr5	70.0	0.029	0.037	0.034	442	410	1
127.	38939	C 45	70.0	0.029	0.068	0.027	401	360	1
128.	38940	C 45	90.0	0.026	0.066	0.024	400	360	1
129.	38976	16MnCr5	100.0	0.035	0.045	0.031	438	410	1
130.	38978	C 45	105.0	0.029	0.046	0.026	370	360	1
131.	38979	St 70.2	83.0	0.033	0.045	0.033	392	360	1
132.	38980	St 70.2	83.0	0.029	0.051	0.028	392	360	1
133.	38981	C 15	80.0	0.025	0.063	0.031	500	450	1
134.	38986	16MnCr5	85.0	0.03	0.046	0.026	426	410	1
135.	39065	16MnCrS5	85.0	0.03	0.066	0.026	450	410	1
136.	39066	16MnCrS5	85.0	0.031	0.032	0.027	426	410	1
137.	39067	482 B	85.0	0.025	0.033	0.027	273	250	1
138.	39069	St 52.3	85.0	0.033	0.045	0.028	456	450	1
139.	39070	C45	85.0	0.032	0.054	0.027	386	360	1
140.	39355	C 45	70.0	0.032	0.065	0.031	388	360	1
141.	39356	C 45	70.0	0.037	0.066	0.032	388	360	1
142.	39357	C 45	70.0	0.03	0.058	0.031	401	360	1
143.	39358	C 45	70.0	0.032	0.067	0.03	401	360	1
144.	39380	C 45	70.0	0.025	0.048	0.031	401	360	1
145.	39709	St 70.2	90.0	0.03	0.044	0.03	284	360	0
146.	39720	St 70.2	90.0	0.03	0.031	0.028	284	360	0

Table 2.
Experimental data (testing data set)

#	Batch number	Grade	FI [mm]	Ca [%]	O [%]	S [%]	v_{15}	v_{15} required	Adeq.
1.	39779	Ck45	90,0	0,03	0,069	0,032	373	360	1
2.	39857	16MnCr5	90,0	0,035	0,041	0,032	430	410	1
3.	39861	482	90,0	0,034	0,056	0,030	256	250	1
4.	39877	16MnCrS5	90,0	0,033	0,05	0,034	441	410	1
5.	39878	482	90,0	0,029	0,045	0,032	256	250	1
6.	39881	St70.2	90,0	0,04	0,069	0,033	390	360	1
7.	39882	42CrMs4	90,0	0,035	0,046	0,029	232	210	1
8.	39884	St70.2	90,0	0,035	0,043	0,028	373	360	1
9.	39964	St52.3	100,0	0,029	0,043	0,028	470	450	1
10.	40034	16MnCrS5	95,0	0,024	0,083	0,030	425	410	1
11.	40038	C15	95,0	0,028	0,068	0,034	465	450	1
12.	40045	16MnCrS5	95,0	0,03	0,052	0,035	425	410	1
13.	40046	16MnCrS5	95,0	0,043	0,075	0,035	425	410	1
14.	40047	16MnCrS5	95,0	0,026	0,056	0,035	425	410	1
15.	40128	16MnCrS5	95,0	0,03	0,07	0,029	425	410	1
16.	40130	St70.2	95,0	0,035	0,075	0,031	385	360	1
17.	40168	16MnCrS5	70,0	0,032	0,05	0,024	424	410	1
18.	40172	C45	70,0	0,035	0,069	0,028	388	360	1
19.	40205	16MnCrS5	95,0	0,036	0,068	0,030	411	410	1
20.	40206	C45	95,0	0,039	0,05	0,030	280	360	0
21.	40207	C45	95,0	0,034	0,061	0,030	373	360	1
22.	40211	C45	95,0	0,034	0,07	0,029	373	360	1
23.	40265	16MnCrS5	90,0	0,034	0,058	0,027	411	410	1
24.	40266	16MnCrS5	90,0	0,032	0,057	0,027	411	410	1
25.	40438	16MnCrS5	90,0	0,029	0,049	0,027	430	410	1
26.	40439	C45	90,0	0,028	0,043	0,028	337	360	0
27.	40477	16MnCrS5	90,0	0,025	0,06	0,024	412	410	1

Out of 27 batches only in two batches the steel was not adequate (i.e. it was not declared to be the steel with extra machinability). The mathematical model (6) correctly predicted machinability (i.e. it returned correct value 0 or 1) of the complete test batches.

5. Conclusions

Due to their specific properties when compared to 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 a smaller cutting tool wear.

In the research the genetic programming was used for predicting the steel machinability. In the proposed concept the mathematical models for verifying the steel machinability are subject to adaptation. Out of 146 values the fittest 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. In the testing phase, the genetically produced model (6) gives the same results as actually found out during the experiment (Table 2). Thus, in this case the reliability was 100%.

Researches have shown that by using the genetic programming method for prediction steel machinability appropriateness it is possible to establish efficient planning and optimizing of production, to reduce handling charges and, finally, to increase the buyer satisfaction due to shorter delivery times.

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