

FORMING RESISTANCE DETERMINATION OF STEEL

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Abstract. Knowledge of the steel forming resistance is very important at all methods of the steel forming. During teaching the subjects “Manufacturing Technology I” and “Basic of Manufacturing Technology” our students get acquainted theoretically (in lectures) and practically (in laboratory practice) with cold forming and with hot working. At practices they can get practically acquainted with chosen technologies of cold forming, namely with shearing, bending, drawing and stamping. In the field of hot working the practice “Experimental determination of forming resistance using the forging test” was prepared. From theory it is known that properties of metals and their alloys vary with their forming. The change of resistance against the irreversible deformation is extremely expressive. At high temperatures the majority of metals and alloys are of better plasticity – the forming resistance is lower than at normal temperature. Laboratory tests were carried out at very different forming temperatures (20 °C, 400 °C, 700 °C and 1000 °C). Forming was made using the fall hammer own design, made in workshops at our department. In this paper the results of three selected steel forming resistance evaluation are published. Steel 1 is unalloyed constructional fine-grained low carbon steel, steel 2 is chrome-molybdenum steel and steel 3 is high speed steel. Using the obtained results the new laboratory practice was prepared and successfully tested for our students.

Keywords: steel, hot working, forming resistance, forging, laboratory tests.

Introduction

The lectures of both subjects include all basic engineering technologies, namely foundry work, forming operations [1], welding [2], soldering and brazing [3], adhesive bonding [4; 5], surface protection [6], plastics processing, engineering metrology and cutting operations [7; 8]. Lectures are completed by the themes carried out in practice, namely the technological process of casting products, non-destructive testing, technological tests, metal hot working, metal cold working, spot welding, bonding of metallic and nonmetallic materials, length and angle measuring, control of gears and threads, measuring of cutting edge temperature at turning etc. For study the students have at disposal beside the own notes from lectures the mimeographed texts. Next sources for study are at disposal in electronic form in the university web [9].

Forming technology pertains to the basic processes of manufacturing technology. The mankind has used forming for a relatively long time. From history not only the arm production (e.g., knives, swords, sabers, rapiers, axes, coats-of-arms, armour sheets and other parts of armour), but also other products (e.g., bars, railings) are universally known. But at that time the producers knew neither the theory nor basis of working. They managed only with the own and their ancestors' experiences. The bases of the metal working theory were formed in the 2nd half of the 19th century. Since that time a lot of pieces of knowledge have been obtained and forming becomes an integral part of the manufacturing technology. By forming not only semi-products for further processing (e.g., sheets, bars, rolled sections) but factory-finished products (e.g., screws, nuts, washers, gear wheels, crankshafts, rails) are made, too. From the theoretical point of view forming can be classified according to temperature, temperature effect, amount of deformation etc. In practice the forming processes are classified according to the applied force. From this point of view we distinguish shearing, bending, drawing, extrusion, stamping, forging, rolling etc. [10-12].

Further we deal with the classification according to the temperature. From theory it is known that properties of metals and their alloys vary with their forming. The change of resistance against the irreversible deformation is extremely expressive. At high temperatures the majority of metals and alloys are of better plasticity – the forming resistance is lower than at normal temperature. Plastic deformation can be realized by two basic procedures:

- by cold forming, when the forming temperature is lower than the recrystallization temperature,
- by hot working, when the forming temperature is higher than the recrystallization temperature.

Both procedures are of advantages and disadvantages and are used in practice [13; 14].

During the teaching our students get acquainted theoretically (in lectures) and practically (in laboratory practice) with cold forming as well as with hot working. At practices of the subjects “Manufacturing Technology I” and “Basic of Manufacturing Technology” they can get practically acquainted with the chosen technologies of cold forming, namely with shearing, bending, drawing and stamping. In the field of hot working the practice “Experimental determination of forming resistance using the forging test” was prepared [11; 15; 16].

Materials and methods

Forming tests make it possible to study a row of partial influences, e.g., the influence of the forming temperature, strain rate, strain energy, dimensions and the shape of the test samples and if need be of the forming plate roughness. With regard to the dedicated time for this practice (90 min) a simplification was necessary. Only the influence of the forming temperature was followed.

The test procedure is the following: Students receive from the teacher the test rolls of about 16 mm diameter and about 16 mm height, from each tested steel [17-19] four pieces. In our tests, three test specimens were used from each material and from each temperature. This allowed us to perform a statistical evaluation of the measured data (see Table 2.). Before the test the students measure using the digital caliper and enlist in test report the roll real diameter d_0 and height h_0 . Then three of rolls are put in the ready for use electric furnaces and are left there for 30 minutes for warming up to the forming temperature (400 °C, 700 °C and 1000 °C). With regard to the safety instructions this operation is carried out exclusively under the teacher’s supervision. The work begins with the rolls forging at the temperature of 20 °C. Using the tongs the samples are put on the fall hammer bottom die placed on the anvil block (weight $m_s = 240$ kg). Using the lever the safety pin is unfasted and the hammer head (weight $m = 39.5$ kg) strikes the sample. The fall hammer design (Fig. 1) makes it possible to choose the falling height. In this case the height of $H = 0.5$ m was chosen.



Fig. 1. Fall hammer [20]

Analogically the tests are carried out at higher temperatures. In this case the time between the samples taking out from the oven and their forming is very important. Because of the relatively quick sample cooling the oven temperatures are a little higher than the demanded forging temperatures. After forging of all rolls their height h is measured. Then the data are computed [11].

The photos of the specimens before and after the test are shown in Fig. 2. Left is the sample before the test. Toward the right are the samples formed at the temperature 20 °C, 400 °C, 700 °C and 1000 °C.



Fig. 2. Specimens before and after the test

The potential energy of the hammer head A_p is computed using the equation (1)

$$A_p = m \cdot g \cdot h = 39.5 \cdot g \cdot 0.5 = 193.7 \text{ J.} \quad (1)$$

In the same way as with other mechanisms used in the field of the manufacturing technology the fall hammer is of some loss in energy. Therefore, at the test samples forming the whole above calculated energy is not exploited and this loss in energy must be taken in consideration. The efficiency of the fall hammer η is calculated using the equation (2)

$$\eta = \frac{m_s}{m + m_s} = \frac{240}{39.5 + 240} = 0.86. \quad (2)$$

The deformation work of the hammer head A_d is calculated using the equation (3)

$$A_d = A_p \cdot \eta = 193.7 \cdot 0.86 = 166.3 \text{ J.} \quad (3)$$

For forming the resistance value for the test samples in form of the cylinder, made from different steels and formed at different temperatures, is calculated using the equation (4)

$$k_o = \frac{A_d}{V_o \cdot \ln \frac{h_0}{h}} \text{ MPa,} \quad (4)$$

where $V_o = \frac{\pi \cdot d_0^2 \cdot h_0}{4}$ – tested roll volume, m^3 .

The knowledge in the forming resistance k_o is very important, because the deformation force depends on its value.

Results and discussion

The tests were carried out using three different steels of different chemical compositions (Table 1) and mechanical values.

Table 1

**Chemical composition of steels according to standards [17-19]
and chemical composition of used steels (weight %)**

Element	Steel 1: ČSN 41 1373	Used steel	Steel 2: ČSN 41 5142	Used steel	Steel 3: ČSN 41 9810	Used steel
C	max. 0.17	0.09	0.38-0.45	0.41	1.20-1.35	1.31
Mn	x	x	0.50-0.80	0.7	Max. 0.45	0.22
Si	x	x	0.17-0.37	0.28	max. 0.45	0.19
Cr	x	x	0.90-1.20	0.94	4.00-4.80	4.58
W	x	x	x	x	10.00-12.00	10.87
Mo	x	x	0.15-0.30	0.2	max. 0.50	0.17
V	x	x	x	x	3.60-4.50	3.98
P	max. 0.045	0.014	max. 0.035	0.019	max. 0.035	0.021
S	max. 0.045	0.018	max. 0.035	0.012	max. 0.035	0.015

Steel 1 [17] is unalloyed constructional fine-grained low carbon steel 11 373 according to the ČSN 41 1373 (corresponds, e.g., to steels S235JRG1 or 1.0036 or USt 37-2). Steel 2 [18] is chrome-molybdenum steel 15 142 according to the ČSN 41 5142 (corresponds, e.g., to steels 42CrMo4 or 1.7225 or CrMo140 FE). Steel 3 [19] is high speed steel 19 810 according to the ČSN 41 9810 (corresponds, e.g., to steels 1.3302 or R9F5).

The results are presented in Table 2 and Fig. 3.

Table 2

Test results

Forming temperature, °C	Forming resistance, MPa		
	Steel 1	Steel 2	Steel 3
20	1344 ± 99	7522 ± 8	21188 ± 91
400	964 ± 32	3239 ± 62	8467 ± 38
700	636 ± 26	1531 ± 76	3784 ± 76
1000	286 ± 18	380 ± 3	907 ± 44

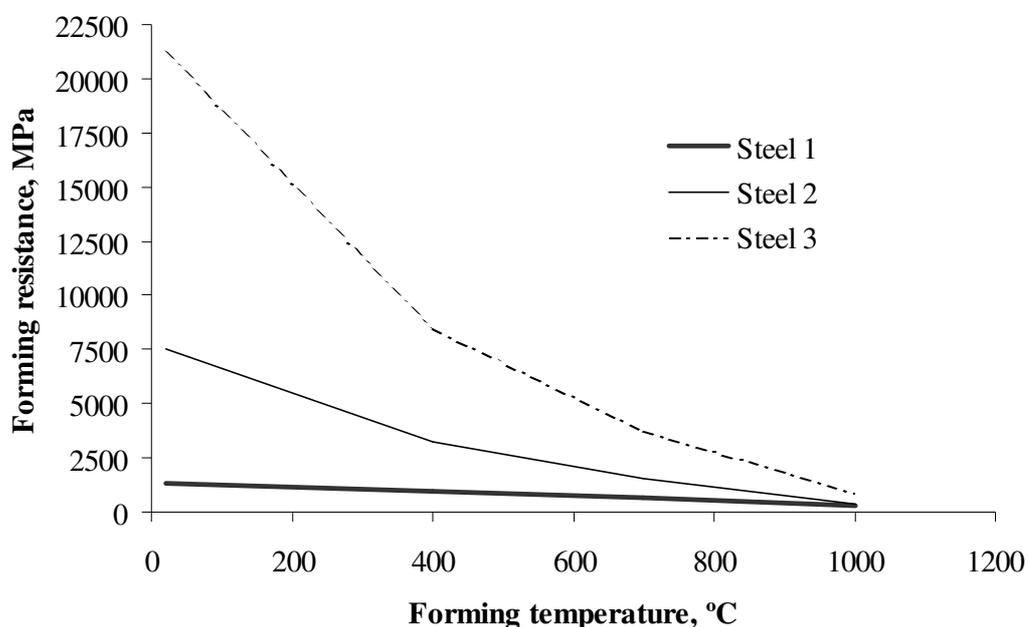


Fig. 3. Test results (standard deviation is demonstrated by the line segments)

From the carried out tests it is evident that at the temperature of 20 °C the steels were of very different forming resistance values – from about 1340 MPa to about 21200 MPa. With increasing the forming temperature the forming resistance of all three steels decreases. At the highest test temperature of 1000 °C the forming resistance values are from about 290 to about 900 MPa.

The aim of the above described experiments was to verify the published literature sources and to find whether it is possible to prepare on this basis the laboratory practice, which can be carried out by students in a matter of 90 minutes. It was determined that by us the measured values are in line with the published data. Further it was determined that at the observance of the above mentioned procedure the laboratory practice completion is in our department conditions real. Therefore, the practice of the title “Forming resistance experimental determination using the forging test” was prepared and tested at teaching.

Conclusions

The paper contains the results of the forming resistance experimental determination using the forging test. The aim was to verify the published literature sources and to get data for the laboratory practice preparation for the students of our faculty.

In the experiments the test samples from three different steels were included. The tests were carried out at different forming temperatures, namely 20 °C, 400 °C, 700 °C and 1000 °C using the fall hammer own design, made in the workshops at our department.

It is possible to state that our tests were in line with the results published by other authors. Using the obtained results the new laboratory practice was prepared and successfully tested for the students of the subjects “Manufacturing technology I” and “Basic of Manufacturing Technology”.

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