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Magnetic forming with heat in a magnetic field

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Abstract: The article focuses on the application of a magnetic field in the forming of low-carbon steel castings. The original solution of the forming device, which was used in the experimental works, is presented. The results of the experimental works confirmed the suitability of its use for the mentioned work.

Keywords: samples, magnetic field, forming, tests.

1 THEORETICAL KNOWLEDGE

In order to achieve the required melting temperature of a certain type of material, it is necessary to supply the appropriate amount of energy. During casting and production of castings, the liquid phase obtained with the help of an energy source (melting furnace) is used, but after casting, the falling temperature of the casting is no longer used. The following text describes how this temperature can be used to optimize the casting and forging process.

A metal with a temperature of T_1 has a temperature of T_2 when cast into a mold. When processed by die forging, on the condition that T_2 is approximately equal to the temperature of T_3, that is, the temperature of T_2 does not differ much from the value of the temperature of T_3, i.e. size of the upper forging temperature, we can process the casting for the purpose of increasing its useful and mechanical properties, up to the limit of T_4, the lower forging temperature. (Fig. 1).

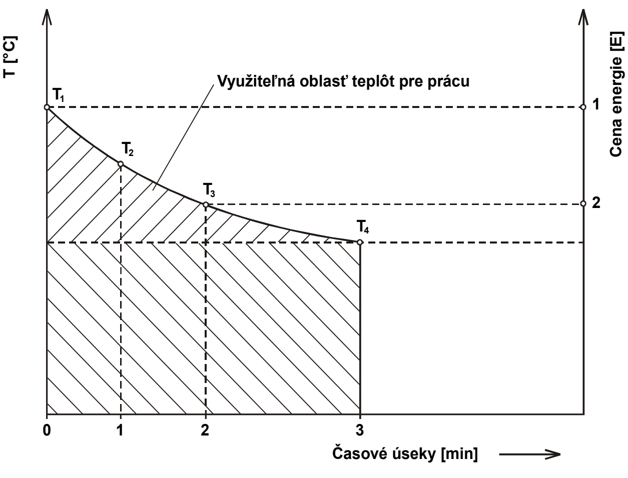

Fig. 1. Illustration of the use of metal temperature for casting and forming

A steel model device was made for experimental verification. Lead was used as an experimental material because the model tests use the properties of lead and its alloys, which at ambient temperature have similar plastic properties as steel at a temperature of 900 °C. Two types of parts (components) were made:

- cylindrical samples with through a continuous hole, five pieces,
- mounted samples also with a continuous hole, five pieces.

Procedure:

- molten metal was poured into the model mold, which was then shaped in the die by pressing pressure.

Findings:

- one heating is enough for both methods,
- the method is also suitable for small-scale production,
- savings in energy costs are obtained.

Limitation:

- with a low range of forging temperatures, there is a risk of damage to the forming tool if the forming time interval is shifted.

The benefit of the solution is the financial effect expressed by cost savings not only of the energy itself, but also of the need for only one heating device. When comparing the consumption of electricity between two furnaces, i.e. a heating furnace and a melting furnace, it can be seen that the power consumption of both devices at a price of € 0.198 per 1 kW is:

1 - melting furnace *K* 360/12 - 100 kW, price € 19.80,

2 - heating furnace *VK* 100*S* - 45 kW, price € 8.91.

This simple comparison shows the economic advantage of the solution, especially with the constant increase in the price of electricity.

1.1 The process of applying a magnetic field

The casting process itself can be done in a magnetic field (Fig. 1). Experimental works as well as theoretical analysis of process events confirm a positive result.

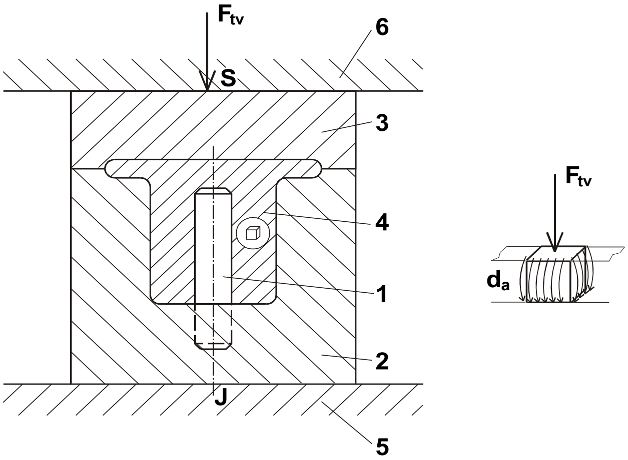

Fig. 2. Schematic of reworking the casting in a magnetic field: 1 - mandrel, 2 - lower part, 3 - upper part, 4 - workpiece, 5 - press table, 6 - frame

In Fig. 2 is a schematic diagram of a casting forming experiment arrangement where magnetic field lines surround the forming region and act on the volume elements. The effect of the magnetic field on the directional solidification of the melt was described above. Similar positive and positive results are realistically expected in this case as well when applying the procedure to practice and production of real parts.

The intention is to show not only the side connected with production technology, but also to partially draw attention to the economy, ecology and the use of unconventional procedures in this area. It will be necessary to know in detail the issue of heat transfer in the mold-casting system.

2 EXPERIMENTAL PART

The production of castings by pressing liquid metal combines the advantages of hot forging technology and pressure casting. The required amount of metal is poured into the stationary lower part of the mold. Movable - the upper part of the mold moves downwards after pouring the liquid metal and begins to push the metal upwards into the gap between the active parts. After the entire cavity is filled, the pressing pressure is transferred to the entire volume of the metal. Crystallization of the casting until complete solidification takes place under pressure, which also results in solidification of the metal [4].

The second alternative to this method is casting with crystallization under pressure. The upper part of the mold (press) covers the entire cross-section of the cavity of the lower mold and the metal is not extruded. The die enters the bottom of the mold just enough to compensate for the shrinkage of the metal. As a result of using the pressure of the die, the casting exactly copies the surface of the mold. The clean and high-quality surface of such a casting is close to the quality of the surface of castings cast under pressure. The advantage of this method is the calm free escape of gases and the fact that the necessity of using an inlet system is eliminated, because the metal is poured directly into the working cavity of the mold.

For experimental work, samples were made of low-carbon steel 12 020. The chemical composition of the steel is: *C* - 0.13%, *Cr* - 0.20%, *Mn* - 0.70%, *Ni* - max 0.25 %. The hardness of the samples was 66.05, 66.10, 66.90, 68.15, 68.30 *HRB*. The sets of rollers were cast in a mold. After reaching the upper forging temperature of 1280 ºC, the actual forming began. 10 pieces with the application and 10 pieces without the application of a magnetic field were formed up to the limit of the lower forging temperature of 750 ºC. The scheme of experiments with the application of a magnetic field is shown in Fig. 3.

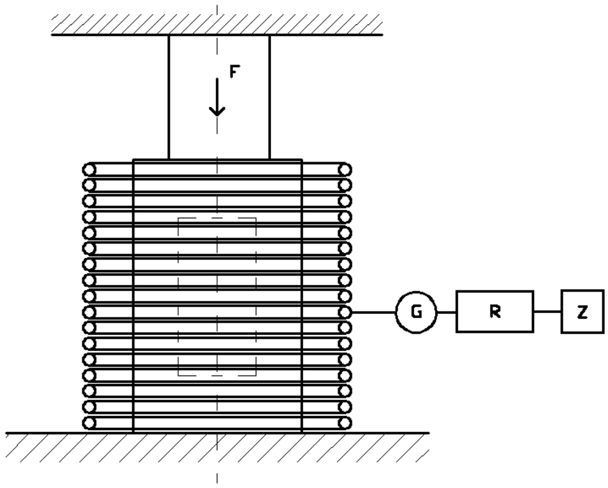

Fig. 3. Scheme of experiments with the application of a magnetic field

Principle:

The work that the source supplied to the circuit from the moment of switching on $t = 0$, $I = 0$, to the assumed moment $t = t, I = I$, is:

$$A = \int_0^t \varepsilon' \cdot I \cdot dt = \int_0^t R \cdot I^2 \cdot dt + \int_0^t \left(L \cdot I \cdot \frac{dI}{dt} \right) \cdot dt \qquad (1)$$

where $\acute{\varepsilon}$ - *DC* electromotive voltage source, $\varepsilon' = R \cdot I + L \cdot \frac{dI}{dt}$.

On the right-hand side, the first term represents *Joule's heat*. The second term for $I = 0$ is non-zero and represents the energy accumulated by the inductance L. It is the energy of the magnetic field and applies to it:

$$E_m = \int_0^I L \cdot I \cdot dI = \frac{1}{2} \cdot L \cdot I^2 \qquad (2)$$

This energy can be expressed using the magnetic field vectors $\boldsymbol{H}$, $\boldsymbol{B}$. The model case of a toroidal coil with current I and number of turns N is used. For the total magnetic flux Φ surrounded by its turn:

$$\Phi = L \cdot I = N \cdot B \cdot S \ . \qquad (3)$$

After substituting for $L{\cdot}I$ in (1) using the relation:

$$H = \frac{N \cdot I}{d} = n \cdot I \,. \tag{4}$$

where d = length of curve $2{\cdot}\pi{\cdot}R$,

n - density of turns, $n = \frac{N}{d}$,

from which $I = \frac{H \cdot d}{N}$ will be:

$$E_m = \frac{1}{2} \cdot L \cdot I \cdot 2 = \frac{1}{2} \cdot \Phi \cdot L = \\ = \frac{1}{2} \cdot H \cdot B \cdot S \cdot d = \frac{1}{2} \cdot H \cdot B \cdot \tau \,. \tag{5}$$

where $\tau = S{\cdot}d$ is the volume of the toroid.

Accumulation of magnetic energy occurs in the circuit when the current increases and is supplied by the current source.

In Fig. 4 is a captured assembly of the experimental forming device.

A detailed description of the construction of the used device and its calculation is in the source [3].

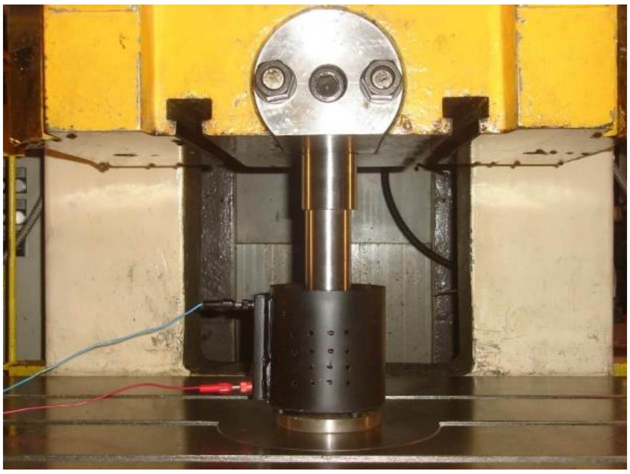

Fig. 4. An experimental device - an assembly

2.1 Testing

2.1.1 Construction of pressure test equipment

In order to carry out the tests, it was necessary to manufacture the test equipment described in the following text. The tool consists of the following basic parts: body pos. 1 where there is a working chamber in which cylindrical samples of metal materials are placed. The second part is the punch list pos. 3 by which the sample is pressed in its longitudinal axis. The punch is housed in a bronze case, pos. 2. The sample is stored in the cavity on the plate pos. 4, which is hardened to 60 *HRC* and ground. The body is screwed to the base plate. A ventilation hole is drilled in the longitudinal axis of the body, necessary for mounting the plate (Fig. 5).

An experiment was carried out in the said facility. Conditions of the experiment: machine - shredder, tool: pressing device.

10 + 10 pieces of cylindrical samples were pressed. The dimensions of the samples were ø18x21 mm. The reduction was chosen to a maximum of 30 %. Figure 6 shows part of the samples after the tests. Tables 1 and 2 show the results of the experiment.

Fig. 5. A test equipment

Fig. 6. Samples after tests performed at various reductions

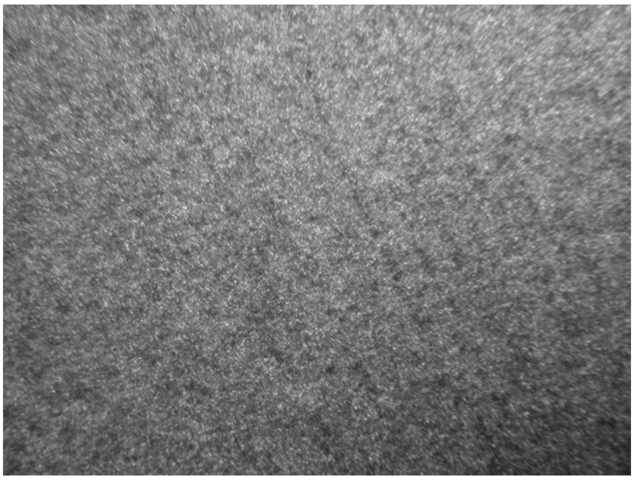

Fig. 7. Metallographic cut of the sample, magnification 100x, etched *Nital* 2 %

According to the data in the tables, it is clear that the tests were carried out in hot conditions. The temperatures are higher than the *Curie temperature*. It follows that when applying a heating amount with a value smaller than the *Curie temperature*, a greater influence of the magnetic field on the forming process can be expected. The tests were only intended to point out the fact that the application of a magnetic field does not have an adverse effect on the forming process as such. Cracks did not occur on any sample out of the entire number of samples. Figure 8 shows the metallographic cut of the sample with a reduction of 30 %. The bulge parameter is listed for addition.

Figure 8 shows a metallographic cut of a sample that has a reduction of 29.55 %. The sample has a pronounced course of compressed fibers. Other cuts are not included, because it would be unnecessary duplication at the expense of space in the text of the work.

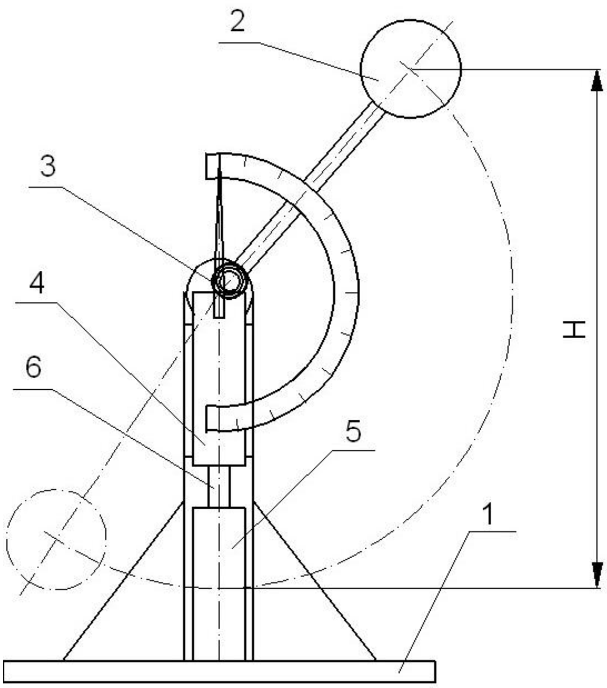

Fig. 8. A test device for detecting transformational resistances

2.1.2 Determination of apparent resistances

Simplified technological tests on samples were used, the aim of which is to determine the final value of the resistance against deformation in an integral way. The test samples are designed in such a way that the state of stress during their deformation is maximally close to uniaxial. The scheme of the device is shown in Fig. 8.

Principle:

The essence is a modified *Sharpy hammer*. Pendulum 2 with a weight of 25 kg has a maximum lift of H = 1.5 m. On the shaft around which the pendulum rotates, a circular cam 3 is fixed, which through a roller bearing acts on member 4, which deforms the test sample 6. After the pendulum swings, the total work consumed during hammering is measured.

During impact forming, the tool hits the formed material at a certain speed. It ranges around 6 m·s^{-1} in the case of thunderbolts. The speed from the moment of impact of the tool starts to decrease, because the work is consumed in shaping the material. After the work done by the falling ram is exhausted, the speed will drop to zero.

Due to the fact that the test is close to static hammering, the evaluation can be done according to a simple relationship:

$$A = K_S \cdot V \cdot \ln \frac{h_0}{h_1} = K_S \cdot V \cdot \varphi \quad [\mathrm{J}], \qquad (6)$$

where A is the transformation work consumed to transform the sample,

K_S - medium deformation resistance (MPa),

V - volume of compressed sample (cm^3),

h_0 - initial height of the compressed sample (mm),

h_1 - height of the sample after compression (mm),

φ - logarithmic degree of transformation.

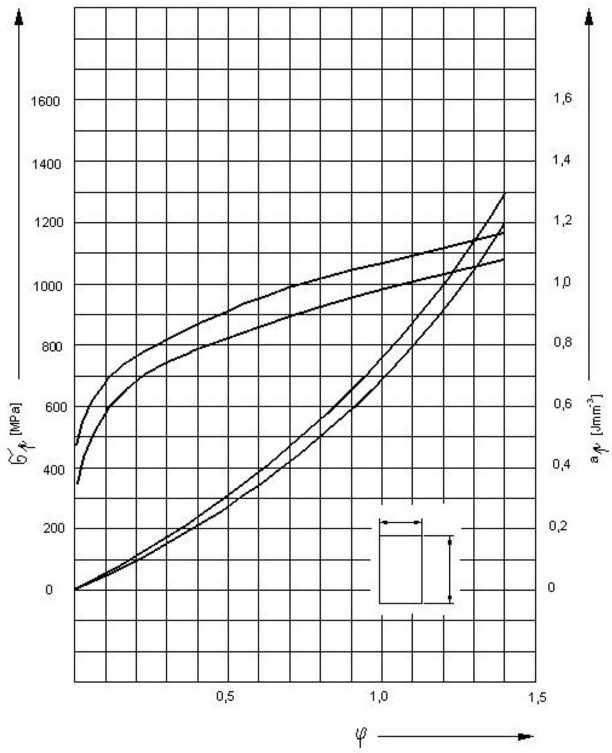

Fig. 9. Curves of deformation resistance of the tested steel

In Fig. 9 shows the dependences of deformation resistances on the logarithmic degree of deformation (these dependences are also called strengthening curves) for individual test stages for steel 12 020. The measured values are the mean values from five measurements.

CONCLUSION

Trends in industry will require the use of unconventional technological procedures, where the latest scientific findings (physics, chemistry) will be applied. Increasing productivity and its indicators in the production of components and functional units will require the use of new progressive procedures that can satisfy the demands of producers and customers.

In the contribution, the effort was to point out the real possibilities of applying physical knowledge to the production process and verifying the device for influencing the forming process with a magnetic field in laboratory conditions, which was accomplished.

From the point of view of intention, the detected differences are insignificant. The magnetic field does not play a significant role in the machining of material exposed to its action in the previous process.

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