MAGNETIC FIELD APPLICATION IN AREA SHEET METAL FORMING

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Abstract

This contribution delivers theoretical analysis of the process and relevant findings related to the above process. Design solutions on used metal sheet holders for forming are presented in this article. In the experimental part we conducted laboratory tests using sheet metal samples. This contribution is complemented with discussion on the presented issue.

Keywords: Magnetism, sheet metal forming, holders, samples, sheet metal

1. INTRODUCTION

Sheet metal forming has occupied a leading position in engineering production for several decades. The main advantages of forming include substantial material savings that have proven very useful and appropriate, given the current pressures (generally and worldwide) on greening the production. An undoubted advantage of forming is its relatively easy process automation. Another great importance of forming technology is that it enables a substantial increase in labour productivity, which is mainly seen in shortened production cycles and reduced laboriousness. Applying new knowledge to manufacturing and exploiting the benefits of forming technologies depend also on the proper design and construction of forming tools. A relatively higher price of forming tools, compared to the price of tools for chip machining, constitutes an obstacle to a more massive penetration and application of forming to the sphere of piece and small-batch production. For a long time researchers have been trying to find ways to introduce this technology to the above sphere. These include the application of new procedures consisting mainly of using physical knowledge and findings that are a huge pool of ideas. In this case, forming is mostly carried out in the so-called non-rigid tools, which encompass such forming tools whose design takes into account the use of new solutions that do not require all-metal tools. This results in minimisation of production costs and shorter time of production preparation. The presented paper belongs to a range of unconventional technological processes of forming. [1, 2, 3, 4, 5]

2. THEORETICAL KNOWLEDGE

The essence of applying the electromagnetic phenomenon was studied by N. Tesla as early as in 1897. This phenomenon was practically applied in 1958 in the forming of parts. Machine tools utilising the principle of electromagnetism began to appear on the market after 1962. The essence of the phenomenon is induction. Electromagnetic field must be formed around the component - conductor to be formed. This requires creating a coil through which energy accumulated in a set of capacitors is discharged. This produces a repulsive force between the coil and the component (conductor), which causes a deforming pulse. The resulting effect depends on the density of vector lines of the electromagnetic field flux. **Figures 1 and 2** schematically show tube forming.

Conventional devices operate with a voltage of 8-15 kV and energy of 12-20 kJ. The discharge time is from four to ten seconds. The forming pressure is usually from 3,500 to 5,000 MPa. [5, 6, 7]

The method is suitable for tube forming (and also for extrusion of rounded threads), for drawing and trimming of sheet metal to a thickness of 2 mm, for connecting cable loops and conductors, for connecting non-metallic materials with metallic ones, and for decorating sheet metal surfaces with a relief. The material to be formed must have a high electrical conductivity - maximum is 10% lower than the conductivity of copper. Forming a material with lower conductivity is only possible after the material is copper-plated. [8, 9, 10]

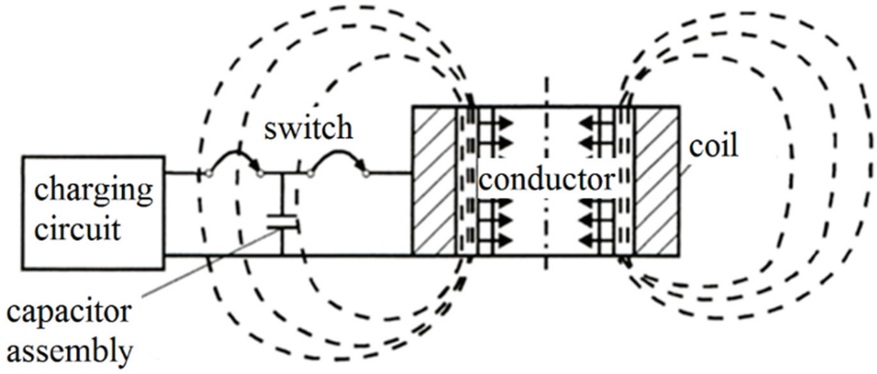

Figure 1 Scheme of an electromagnetic method used in tube forming

Great impulse forces act on the component as well as on the coil. Therefore, coils are manufactured in two types: permanent coils (pre-stressed, insulated with synthetic resin with glass fibre covered with beryllium and copper), and temporary coils that are destroyed at each work step (these coils are manufactured as simple as possible, and are relatively cheap).

The above method allows forming even such materials that have been difficult to form so far. This method results in more forming (reshaping), which eliminates the need for annealing and additional machining. Maintenance is inexpensive because the device does not include any moving parts.

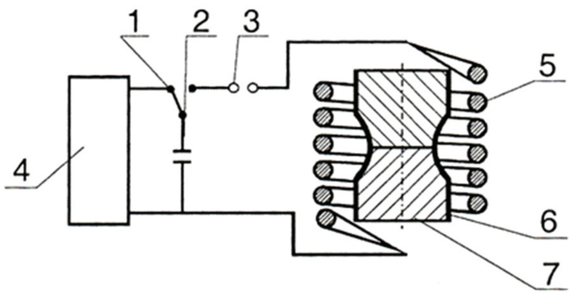

Figure 2 Scheme of electromagnetic pipe narrowing: 1- switch, 2 - capacitors, 3 - spark gap, 4 - power supply, 5 - inductor, 6 - pipe, 7 - calibre

2.1. Possible solution

The question is whether it is possible to replace conventional methods of forming by other, i.e. unconventional methods using magnetisation processes. The term “magnetisation process” generally includes any change in the magnetic state of the substance. In the narrower sense, the term “magnetisation process” usually includes changes in the magnetic state that are caused by the processes in the domain structure of ferromagnetic or ferrimagnetic materials, especially by a shift of domain walls and rotation of magnetic polarisation vector. [11, 12, 13, 14]

3. EXPERIMENTAL WORK

3.1. Sheet metal forming in an open magnetic field

Figure 3 shows a schematic of a component forming using an electromagnet.

The forming force f_n is induced by the forming machine. When we consider the size of the forming force as a factor directly dependent on the forming machine possibilities, we can utilise magnetisation processes in the procedure. The size of the electromagnetic force has its share in contributing to lowering the value of the total forming force f_k. From the above it follows that theoretically we can take into account the contribution of the electromagnet force f_{em} when bending to the value f_n. All this has its importance, and the process can be realised this way. However, the problem cannot be formulated only in the sense that it can be done.

According to the diagram shown in **Figure 3** we designed and built an experimental device, consisting of a bending tool with a created magnetic field during the bending process.

The electromagnetic field was created using electrical current U = 12 V; I = 5 A; the active part of the tool was made of steel, and the bottom section was made of non-magnetic material (duralumin). [15]

We bent 20 pcs of samples, measuring 30 x 72 mm, with a thickness of 0.3 mm - l0 pcs, and of 0.4 mm - 10 pcs. During the experiment, it was not possible to objectively sense the forming force (which was caused by objective reasons). The above described process can be regarded as a suitable step towards further addressing, solving and development of this issue.

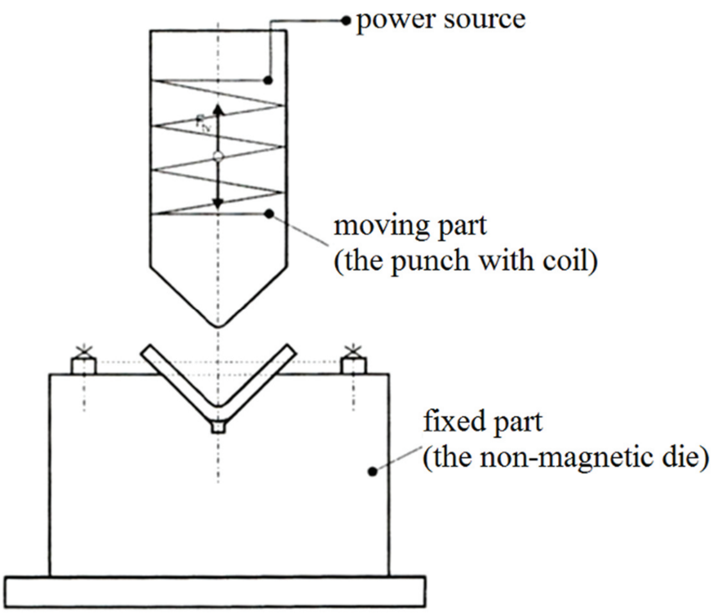

Figure 3 Scheme of the bending process in an open magnetic field

3.1.1. Findings and restrictive process conditions

Restrictive conditions and findings of the process can be formulated as follows:

1) with decreasing material thickness in the bending process, the electromagnetic field becomes a decisive factor due to its effect (possibility of forming very thin sheets and foils),
2) the lower part of the bending die relatively quickly wears out (the need to find a suitable material),
3) the process can be described using the following formula:

Magnetic induction is:

$$\bar{B} = \int_{-\frac{l}{2}a}^{\frac{l}{2}a} \frac{\mu_0 \,.\, I \,.\, R^2}{2\,(R^2 + x^2)^{3/2}} \,.\, \frac{z}{l}\,dx = \frac{\mu_0 \,.\, I \,.\, z}{2l}\left[\frac{\frac{l}{2} - a}{R^2 + \left(-\frac{l}{2} + a\right)^2} + \frac{\frac{l}{2} + 2}{\sqrt{R^2 + \left(\frac{l}{2} + a\right)^a}}\right]$$

where: μ_0 - permeability of the medium, *I* - current, *R* - resistance, *Z* - number of turns (coils), *l* - length of thread, *a* - distance,

4) in terms of geometry and dimensions there is no difference between these pressings and those formed by a conventional bending die.

3.2. Forming in a magnetic field in a laboratory electromagnet

In contrast to the above-mentioned process, the following method is different in that samples of sheet metal were clamped in a special support (**Figure 4**), and therefore were not bent in a tool.

Figure 4 Arrangement

When investigating plastic deformation due to the magnetic field we used as samples sheet metal pieces having a thickness between 0.3 and 0.5 mm, and having chemical compositions shown in **Table 1**.

Table 1 Chemical composition of the material of samples [%]

Material	Sample	C	S	P	Mn
11 321	**A**	0.10	0.035	0.035	0.40
11 373	**B**	0.22	0.05	0.050	-
11 375	**C**	0.20	0.05	0.050	-

The equipment to conduct experiments included a laboratory electromagnet from the Department of Physics of Faculty of Electrical Engineering, University of Žilina. The distance of magnet poles was 20 mm. **Figure 5** and **Figure 6** shows a wiring diagram used in the experiment.

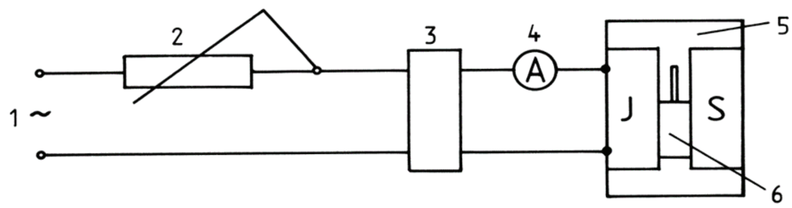

Figure 5 Wiring diagram of devices during the experiment: 1 - power source, 2 - rheostat, 3 - switchboard, 4 - ammeter, 5 - electromagnet, 6 - sample holder

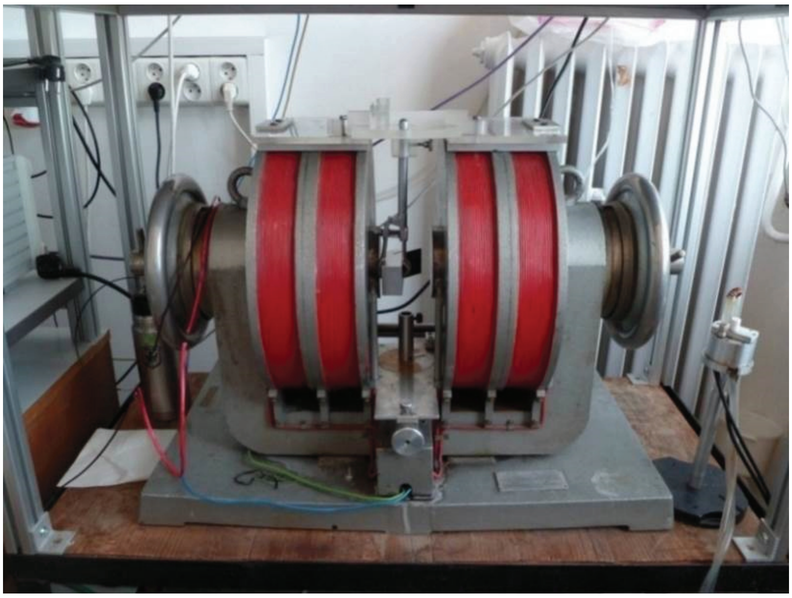

Figure 6 View of the experimental workplace

We monitored the following indicators: change in the sample shape, the time it takes to induce plastic deformation, and we also evaluated the sample shapes. The magnetic field size was I T. Plastic deformation was achieved within seven seconds, but to the maximum depth of 0.5 mm. The graph in **Figure 7** illustrates the time dependence of achieving plastic deformation on the sheet metal thickness.

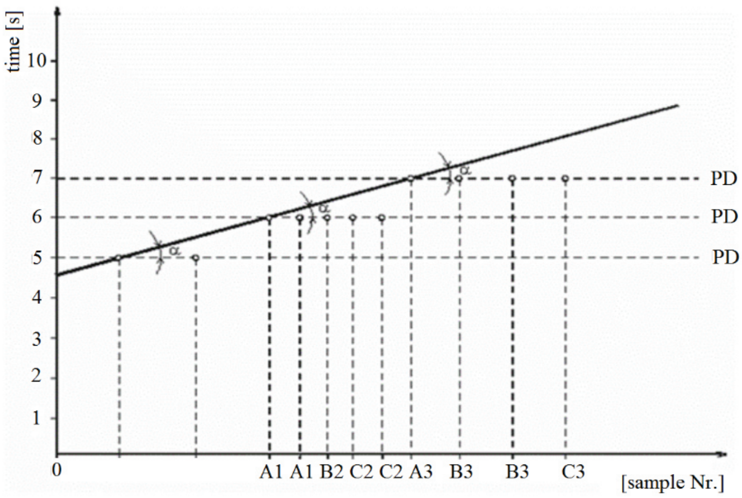

Figure 7 Graph showing the dependence between the material thickness and the time to achieve plastic deformation - PD

It is essentially a directly proportional increase in the time to achieve plastic deformation by the action of the magnetic field on the sample. The magnetic field size of 1T is already insufficient for sheet metal thickness ≥ 0.5 mm. The samples achieved only the domain of reversible deformation, i.e. they never exceeded the yield strength. After the application of the magnetic field we observed springing of the samples. A limiting condition for the use of the above forming method is the material thickness. It was also confirmed that the chemical composition of the material commonly used in the field of sheet metal manufacturing and forming industry does not play a significant role in this method of forming. [11,12] *Samples with a thickness of less than 0.5 mm are suitable for such forming process conditions, and they can be processed by the bending technology in a magnetic field.*

4. FINDINGS

The intention was to bend the samples at an angle of 15°. **Figure 8** shows the samples after forming in a magnetic field. **Table 2** shows the sample measurement results. Deviations from the chosen angle were between -0°41'26" and 3°14'59". This variance is relatively significant, but it can be certainly corrected by improving the process precision in further experiments.

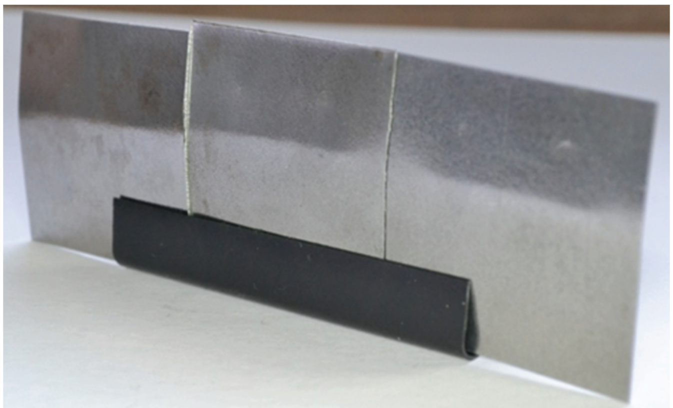

Figure 8 Holder with an angle of 15° used in experiments

Table 2 Sizes of the angles achieved in the experiment

Sample	Measured angle	Nominal angle	Difference
A1	13° 6'52"	10° 0' 0"	3° 6'52"
A2	12° 6'10"	10° 0' 0"	2° 6'10"
A3	12° 6'20"	10° 0' 0"	2° 6'20"
B1	8°52'37"	10° 0' 0"	-1° 7'23"
B2	13°14'59"	10° 0' 0"	3°14'59
B3	12°54'20"	10° 0' 0"	2°54'20"
B4	13° 5'25"	10° 0' 0"	3° 5'25"
C1	12°11'16"	10° 0' 0"	2°11'16"
C2	9°18'34"	10° 0' 0"	0°41'26"
C3	12°15'42"	10° 0' 0"	2°15'42"
C4	9°18'34"	10° 0' 0"	0°41'26"

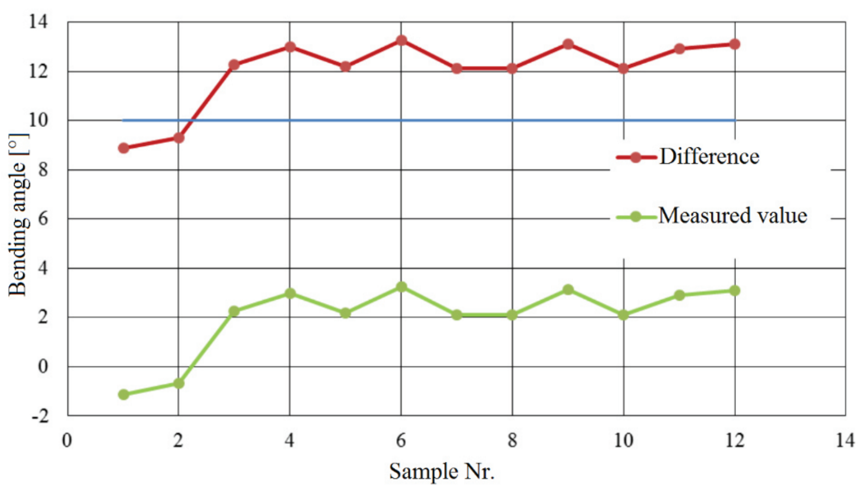

Figure 9 Graph

5. CONCLUSION

We presented two methods of experimental verification of the suitability of applying a magnetic field in the sphere of sheet metal forming. The above procedures need further development and optimisation, so that they could be applied first to small-batch manufacture of sheet metal components and then in their serial production. The engineering production most frequently utilises ferromagnetic material. The advantages of solutions using the magnetic effect and properties also include their ecologically clean output.

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