COLD PLASTIC DEFORMATION IN ELECTROMAGNETIC FIELD

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ABSTRACT: This paper highlights the influence of the cold plastic deformation process in electromagnetic field upon the microstructure and the hardness of the deformed metallic materials.

KEY WORDS: electromagnetic field deformation, hardness, microstructure.

1. INTRODUCTION

The first high-intensity impulsive electromagnetic fields were obtained in 1920 by the Russian scientist P.L. Kapitza [1, 2], but with no immediate practical applications.

The first practical applications of impulsive electromagnetic fields took place in 1958, when the known processes of machining metallic materials, were no longer able to satisfy the new requirements imposed for parts in the aerospace industry.

The process was patented by U.S. scientists in 1959 and was applied in the aerospace industry for the deformation of high resistance alloys, which are used to build some rocket parts, for the execution of assemblies between metallic and nonmetallic parts or between parts of hard-weldable materials, parts which operate under special conditions.

The principle according to which most of the installations of deformation in electromagnetic field operate is based on the electromagnetic induction law, phenomenon that produces electromotive voltages (thus electric currents) in conductors located in variable electromagnetic fields.

The direction of the induced current i_2 is determined with Lenz law and is oriented so that the electromagnetic field around it opposes the inducing electromagnetic field, created by the inductor current i_1, that flows through the solenoid coil.

Since the electromagnetic field and the induced current are perpendicular to each other, a force acts, according to Laplace law, on the conductor with the ***ds*** length, found in the induction field ***B*** and crossed by the $\boldsymbol{i_2}$ current.

This force forms a straight trihedral together with ***ds*** and ***B*** vectors (fig.1).

As a result, the conductors through which the two currents (the inductor and the induced ones) flow, will repel each other.

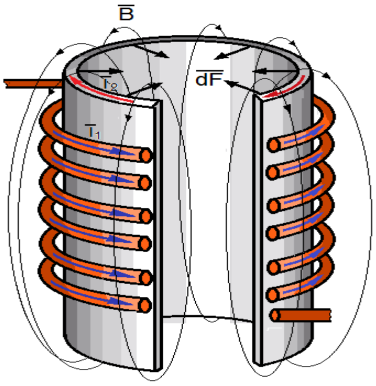


Figure 1. The principle of electromagnetic induction

The plastic deformation machining in electromagnetic field is based on the mutual repel of those two electromagnetic fields created by the inductor current $\boldsymbol{i_1}$ (which flows through the tool-coil) and by the induced current $\boldsymbol{i_2}$ (which flows through the semi-product under processing).

If the acceleration of the semi-product's material is high enough to exceed the yield stress, then the deformations remain permanent, resulting in the change of the semi-product's shape.

Another series of electromagnetic field deformation systems operate on the so-called "contact principle" [1, 2, 3]. These systems are based on one of the Ampere's laws, according to which two parallel conductors crossed by opposite-direction electric currents will repel each other.

Designing such a circuit, in which the current flows through the tool-coil in one direction and through the semi-product in the opposite direction will create conditions for changing the semi-product's shape (fig.2).

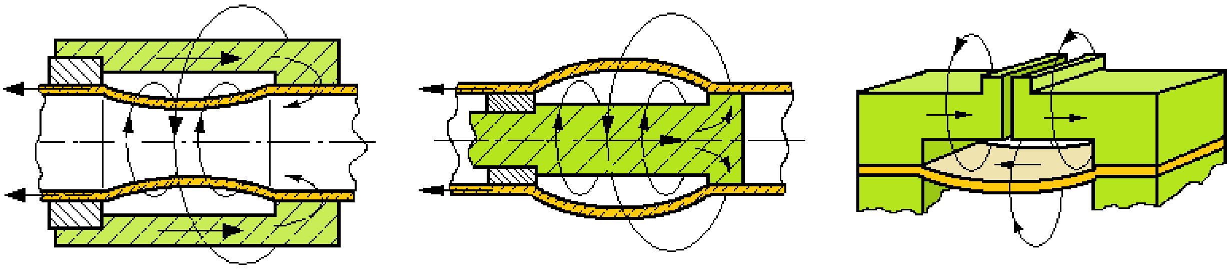


Figure 2. The “contact” principle

The equipments that work according to this operating principle can be more economical than the ones based on the electromagnetic induction principle, due to the circuit’s simplicity and thus, to the lower energy losses.

However, such equipments are less common because of their fewer processing possibilities.

2. PROCESS PARAMETERS

The thorough study of the electromagnetic field deformation process requires the knowledge of both the mechanics of a dynamic deformation process and of the high-power coupled circuits, in which the parameters vary during the process.

The principle scheme of such an installation is generally composed of two circuits (fig.3) [1, 2, 3]:

- the charging circuit ***I***, which is composed of the energy source ***S***, the voltage-increasing transformer ***Tr***, the rectifier bridge ***R*** and the battery of capacitors ***C***;

- the discharge circuit ***II***, which contains the battery of capacitors ***C***, the locking system of circuit ***E*** (of spark gap type), the induction coil ***B*** (the tool), the semi-product ***P*** and the switch ***K***.

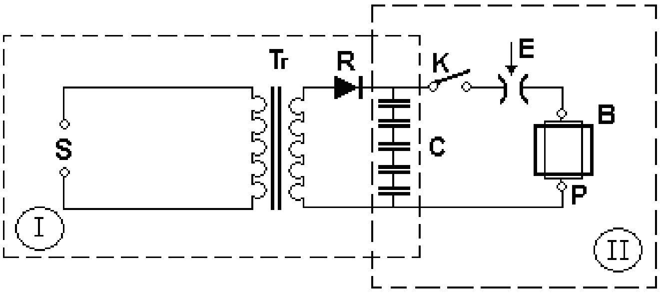


Figure 3. The principle scheme of an installation

Knowing the electromagnetic forces which characterize this deformation process, the influences of the installation’s electric parameters, of the tool’s and semi-product’s geometrical parameters, of the technological parameters etc. upon the deformation degree, upon the force and upon the mechanical work consumed, means accepting a certain equivalent scheme of the discharge circuit (fig.4).

Thus, equating the system composed of the inductor coil and the semi-product with a transformer (fig.4), the equivalent scheme of the discharge circuit will consist in: R_1 and L_1 - the resistance and respectively, the impedance of the discharge circuit (the transformer’s primary circuit); R_2 and L_2 - the resistance and the impedance of the semi-product (the transformer’s secondary circuit).

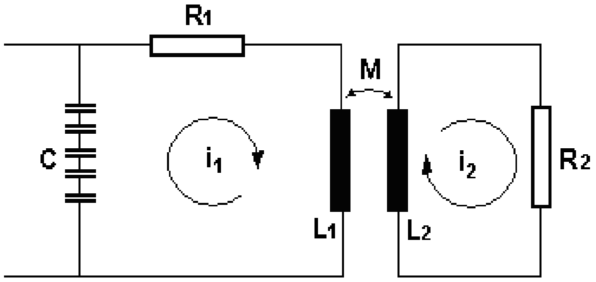


Figure 4. The discharge circuit scheme

When the current i_1 flows through the transformer’s primary circuit (the tool-coil), the electromagnetic flux created by the L_1 coil induces the i_2 current in the transformer’s secondary circuit (the workpiece).

This current creates an electromagnetic flux which is the opposite of the inductor one.

The mutual repelling action of the two thus-created electromagnetic fields constitutes the principle that underlies metals’ processing in electromagnetic field.

The movement of a conductor (the workpiece) in the electromagnetic field created by the tool-coil induces in the latter an electromotive voltage that has negative effects on the energy yield.

Experimental results have revealed that the influence of this tension on the deformation degree is insignificant from the practical point of view, because of the following reasons:

- in the deformation process, it is used the first impulse's energy, which is also the highest (the current varies on a strongly damped sinusoid [1, 2]). As a result, the negative impact of the electromotive voltage, induced in the inductor coil by the workpiece's walls movement occurs after the workpiece has been practically deformed;

- having been deformed, the workpiece moves away from the tool-coil and the following impulses' energy, of lower values, only warms up the workpiece;

- as a result of the deformation, the part has hardened and so, for a further deforming, we need a higher energy than the one corresponding to the first impulse.

Based on the above-mentioned, we can conclude, at least for the practical cases, that the electromotive tension induced in the tool-coil, due to the workpiece's walls movement, can be neglected.

3. PROCESSING EQUIPMENTS IN ELECTROMAGNETIC FIELD

The electric schemes that the deformation installations in electromagnetic field are based on are generally simple (fig.5), their complexity degree depending on the intended use (research or production) and on the automation degree of the entire manufacturing process.

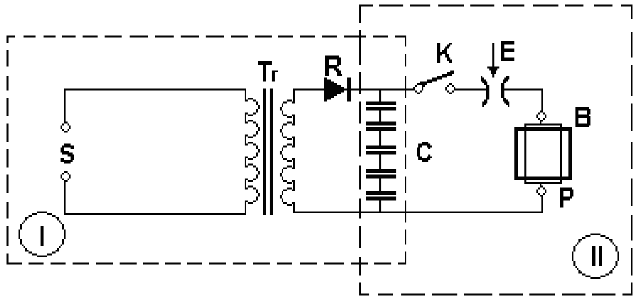


Figure 5. Classical Equipment

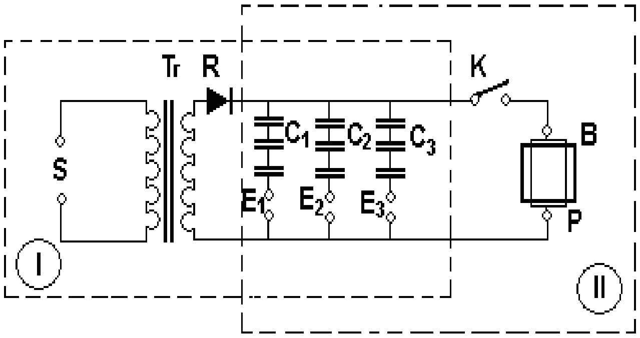


Figure 6. Equipment with modulated battery of capacitors

The large variety of parts and materials machinable using electromagnetic field plastic deformation imposed a variety of functional schemes, meant to adapt the principle scheme to the specific processing conditions.

Consequently, there were designed equipments that have the battery of capacitors in a modulated system (fig.6), with the possibility of coupling an adequate number of modules, depending on the deformation energy needed.

Other equipments have the potential to double the amount of energy accumulated in the battery of capacitors (fig.7).

For the processing of hard-deformable materials (titanium or beryllium alloys etc.) there were designed more complex functional schemes, that additionally have a circuit for previously heating the materials under processing (fig.8).

The two circuits, the deformation circuit **I** and the heating one **II**, are programmed so that the deformation impulse is sent only at the moment when the heated material has reached the state of plasticity that enables the achievement of the desired deformation

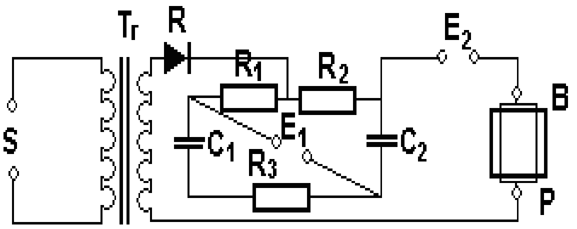


Figure 7. Equipment with two batteries of capacitors

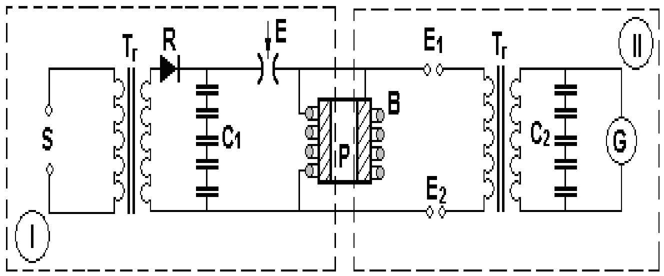


Figure 8. Equipment with a circuit for previously heating the workpiece

Based on the scheme presented in Figure 5, in the TCM department of the IMST faculty – Politehnica University of Bucharest, there were made several cold plastic deformation equipments, of DEMARO type (fig.9) [2, 3].

Figure 9. Equipment for deformation in electromagnetic field

4. INFLUENCE OF THE DEFORMATION PROCESS ON THE MICROSTRUCTURE AND HARDNESS OF THE DEFORMED WORKPIECE

The cold plastic deformation process, by its mechanism, leads to a change in the internal structure of the material under deformation, with direct influences on its physical-mechanical properties, phenomenon known as hardening.

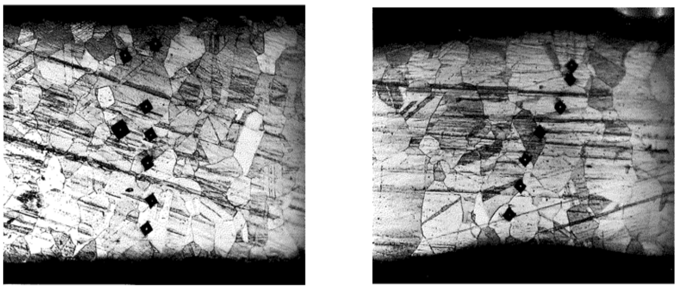


Figure 10. Measurement of hardness

The most important consequence of this is the increase of the mechanical resistance and the corresponding decrease of plasticity.

In this paper, there has been studied the influence of the electromagnetic field deformation upon one of the hardening's consequences, namely the hardness of the deformed material.

To this purpose, the Vickers hardness values were measured in six different points on the material's thickness (fig.10), at various levels of charge of the capacitors battery (Table 1), in the case of inflating a tubular piece made of brass [3,4].

The following conclusions were highlighted:

- the hardness of the deformed workpiece is higher than the one of the undeformed part (fig.11);
- the hardness increases with the increase of the energy used in deformation (fig.12);

Table 1. Hardness variation depending on the discharge voltage

Experiment	Charging voltage [KV]	Deformation energy [KJ]	Hardness HV (50 gr.)							
			1	2	3	4	5	6	ΔHV	Average
0	Undeformed piece		90	85	78	76	88	90	14	84,50
1	3,3	0,35	95	93	97	93	92	95	5	94,17
2	3,5	0,4	110	106	109	110	105	105	5	107,50
3	3,8	0,46	114	113	113	112	110	113	5	112,50
4	4,3	0,59	129	128	130	131	128	129	3	129,17
5	4,5	0,63	135	136	135	134	135	134	2	134,83
6	4,9	0,77	146	148	147	148	147	146	2	147,00
7	5,5	0,97	149	150	149	149	149	150	1	149,33
8	6	1,19	152	151	152	152	151	152	1	151,67

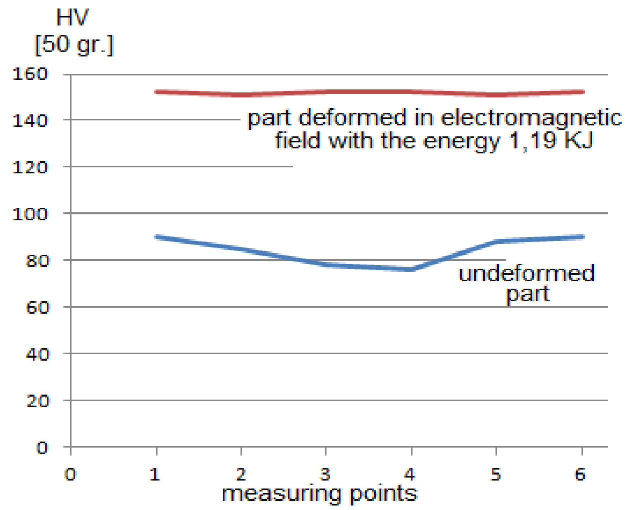


Figure 11. The variation of hardness in the deformed parts

- the hardness remains approximately constant on the thickness of the material deformed in electromagnetic field (the variations that occur are due to the specific point where the hardness has been measured - solid solution, precipitated constituent and so on, fig.11).

Comparing the hardness values measured (in five points on the material's thickness) on parts made of the same material (brass), deformed at the same deformation degree, by classical inflating, in electromagnetic field (table 2), it has been found that [3,4]:

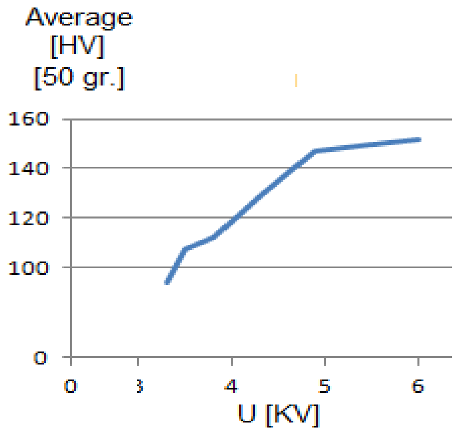


Figure 12. Hardness variation depending on the discharge voltage

- the hardness of the undeformed piece is lower than the one of the deformed pieces;
- the average hardness of the workpiece deformed by the classical procedure is much higher (47%) than the one of the workpiece deformed in electromagnetic field;
- the hardness of the classically deformed piece is higher on the exterior, at the contact with the active surfaces of the deforming elements (Fig.13);
- the hardness remains approximately constant on the thickness of the material deformed in electromagnetic field.

Table 2. Hardness variation in material thickness

Experiment	**Hardness HV (100 gr.)**						
	1	2	3	4	5	6	Average
Undeformed piece	80	82	82	83	81	82	81,67
Classically deformed piece	194	191	181	187	194	195	190,33
Piece deformed in electromagnetic field	130	131	128	127	131	130	128,83

From the technical point of view, the existence of a lower hardness (for the same deformation degree) of the parts deformed in electromagnetic field, represents an advantage, as it allows further plastic deformation, without the need for intermediate heat treatments.

Any process of cold plastic deformation inevitably modifies the microstructure of the deformed material.

Therefore, in this paper, there has been also studied the influence of the electromagnetic field deformation process upon the microstructure of the deformed material.

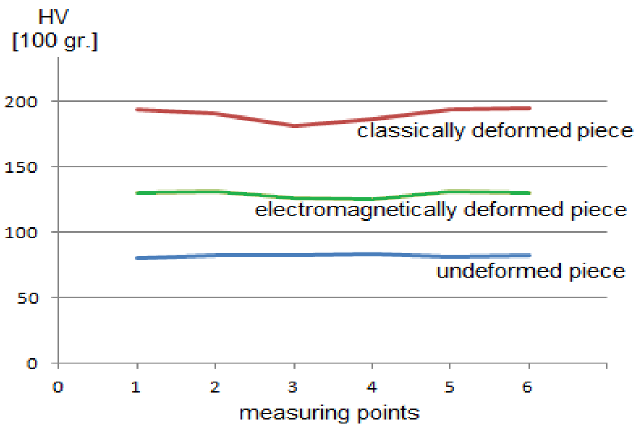
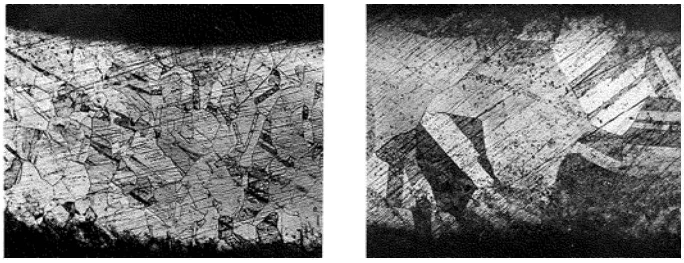


Figure 13. The variation of hardness

To this aim, it has been analyzed the microstructure of the parts made of aluminium, copper and brass, deformed with the same deformation degree, using the classical drawing procedure and the electromagnetic field drawing.

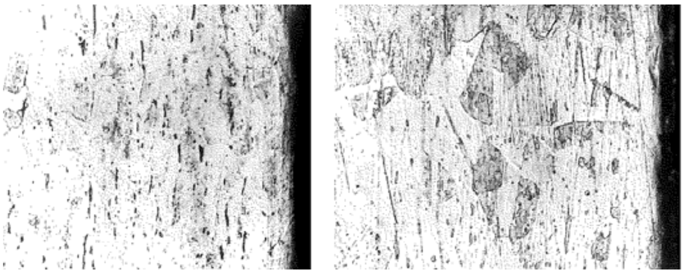
The experimental results revealed an obvious tendency of grains' increasing in the case of the material deformed in electromagnetic field as compared with the one deformed by the classical procedure (fig.14).

Copper



a b

Aluminium



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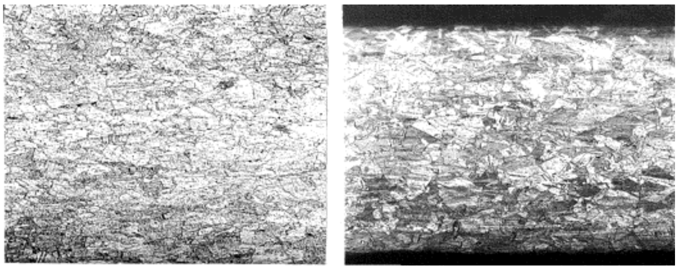
Brass



a b

Figure 14. Classically (a) and electromagnetically (b) deformed material

Since in the electromagnetic field deformation process, the temperature does not exceeding 100°C [2], so it does not exceed the recrystallization temperature that could have changed the microstructure, it obviously results that another factor produced this change.

The grains' increase in case of the materials deformed in electromagnetic field can be attributed to the combined action of the high deformation speed (>300m/sec), of the temperature and of the interaction between the exterior magnetic field and the crystalline network's one, which can lead to an increased mobility of the atoms and to the annexation of the small grains to the large ones.

This structure, with enlarged grains, leads to a reduced tenacity and to an increased corrosion susceptibility of the materials deformed in electromagnetic field.

5. CONCLUSIONS

The electromagnetic field plastic deformation processes, characterized by the deformation energy's release in a very short time interval (very high deformation speed), ensure the achievement of higher degrees of deformation than in the case of the classical processes.

These procedures do not replace the classical ones, but they complete the range of processes, opportunities and materials workable by this method.

6. REFERENCES

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