

## ALLOYING WITH ELECTRON BEAM OF SOME SURFACES ON PIECES MADE BY NON-STRENGTHEN MATERIALS

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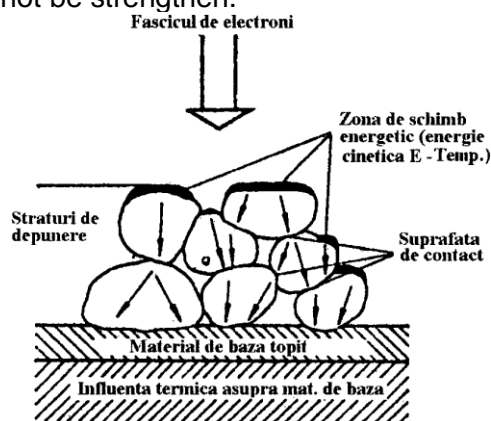
**Abstract:** This report presents the results of the investigations concerning the use of the process of alloying with electron beam for hardening of some surfaces on pieces that, electro-technical standpoint speaking, are made by non-strengthen materials. These investigations show a high interest being a solution to replace the classic technology used till now, in the process of hardening of the mechanical stressed zone on a non-tempered material, by hardened disassembled boards, a very expensive and less reliable method with a modern one concerning the hardening by alloying with electron beam, very economical, reliable method, which leads to the increase of life time of electro technical components of switch-over apparatus.

**Keywords:** HAEB - Hardening by alloying with electron beam, HEB – hardening with electron beam, hardness, alloying, alloying powder, alloyed tapes, hardened patch.

### 1. INTRODUCTION

The modern processes of superficial treatment of strengthen and non-strengthen metals, made to obtain a high hardness on the bombardment zone, against the other material zones, were called by the author HARDNESS [1, 2].

**Electron beam alloying** (DAFE) is the hardening process at the surface, by enriching the basis material with selected elements presented as powder or thin sheet, with the purpose of wearing protection by growing the superficial hardness on a controlled thickness. The transformation of superficial structure of both the added and basis material takes place in a liquid phase (fig.1) on certain deepness. It is usually used for strengthen steels but also for those that cannot be strengthen.



**Fig.1. Hardening by alloying of both melted basis material and the added one on a certain depth.**

### 2. METALLURGY OF ALLOYING WITH ELECTRON BEAM

The particularities of processes which occur during the alloying, against the others processing methods by heating, ask the addition at the classical metallurgy of a new chapter, those of metallurgy of alloying with electron beam.

The alloying process takes place by melting the zone where the electron beam makes contact with the material. In this point, a little melting bath occurs, and here, the alloying preselected elements and the basic material merge.

Specific alloying and micro-alloying with electron beam is the fact that the materials melting are produced very quickly, only in the zone of the contact between the electron beam and the material, the other material staying cool. In the adjacent zone of the melted one, a conduction soft heating occurs. The cooling of melted materials happens instantaneous to behind the electron beam, through the cooled mass of material, with a velocity of approximated at 10.000°C/s.

#### a) The influence of the alloying elements

Generally, the influence of the alloying elements in the electron beam process is the same with those of classical alloying of steels. Carbon is the element with the highest influence in the alloying-hardness process. The elements with high vaporization pressure like magnesium, carbides and especially

wolfram carbide are difficult to use in alloying with electron beam process because they vaporize in the vacuum work (alloying) room.

**b) Unwished phenomenon that take place during the alloying**

**Expulsion of the powder** conducts to the obtaining of an irregular alloyed layer and implicitly of some inferior mechanical performances compared on those settled.

For the obtaining of an uniform alloyed layer all the powder elements must adhere one to the others and all must adhere at the basic material.

**Burning of the very fine powder** is another unwished phenomenon. Is the subject of particles with dimensions lower than those with medium ones, appreciatively  $40\mu\text{m}\pm 5\%$ , as well as some impurities.

To escape this phenomenon, is recommended that when the power is siftered the sub-dimensional elements must be eliminated and the power quality must be conforming to STAS no.12390-25.

**Repression of the liquid material** occurs because the phenomenon of creation of vapor crater, as a result of the forces which act against the melted surface at high specific power. This phenomenon must be avoided. So, the choice of the electro-technological parameters values must take into account both the powder characteristics and the basic material ones.

**c) Alloying defects**

When the alloying with electron beam takes place, some defects could appear: porosity encouraged by the gazes and alloying elements vaporization in vacuum and by the extremely rapid return to the solid state; cracking has a major importance and appears because thermal tensions, and are due to the quickly heating, but especially to the very quickly cooling.

**3. THE CLASSICAL METHOD**

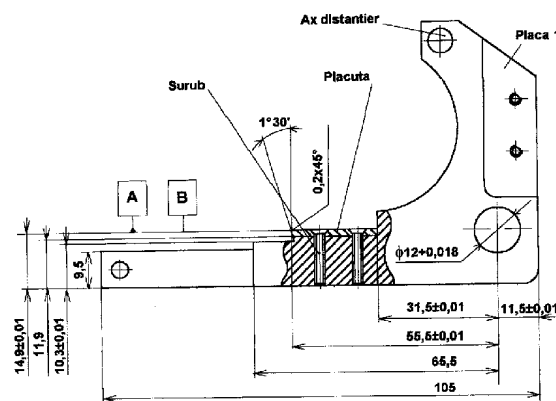
The researches show a high interest and are conducted by the author on S. Fork, main component of ultra-fast IUCC switches of direct current, produced in serial line by SC ICPE SA Bucharest.

The components S. Fork, Board 1 and 2, are made in stainless steel 10 NiCr 16 STAS 3583-86, non-magnetic and non-strengthen. Nowadays, hardness of superficies A and B

fig.2, is realized by making 2 boards in steel OLC 45, treated by hardness and return to 35-40 HRC and sited by screws on the marks board 1 and board 2. As a whole, fig.2, is set correctly at the quota of  $14,9 \pm 0,01$ .

The existing solution is valuable and is used generally as a switches component and especially of those of IUCC series. Because some additional marks and technological processes for hardening of A and B surfaces, fig.2, there are some disadvantages such are: the make up of tow  $4 \times 24 \times 6\text{mm}$  in steel type OLC45, hardness and return of the board to 35-40 HRC, the removal of slag resulted after thermal treatment of boards by additional technological processes, perforate and thread of boards 1 and 2.

Gathering together the boards by screws leads to the modification of the rectified quota of  $14,9 \pm 0,01$  that performs the deterioration of the gadget, which acts the switch.



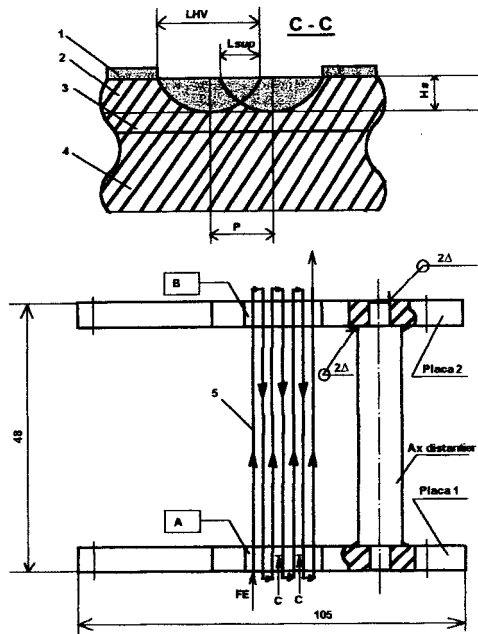
**Fig.2. S. Fork (sideway view) – hardening of A and B surfaces by the classic method.**

**4. THE METHOD OF ALLOYING BY ELECTRON BEAM**

The method consists in attainment of hard layers at the surfaces A and B, fig.3, by alloying with electron beam. This method eliminates all disadvantages and technological processes shown at item 3. In additional, it eliminates the materials in which the boards are made too, the catch screws, effecting important savings.

Also, this method eliminates the main disadvantage from the existing solution that implies the transformation of the removable solution in an immovable one, putting out the possibility of getting damaged of quota of  $14,9 \pm 0,01$  by loosen the effect of screws during the work. The common of two methods

is the rectification process at the quota of  $14,9 \pm 0,01$ , which is performed generally for the attainment of the quality of A and B surfaces. During the alloying process the piece Fork doesn't change its form. The process is rapid with a very high control of process parameters.



**Fig.3. S. Fork (over view) – alloying schema of A and B surfaces.**

Figure 3 shows the schema of hardening by alloying, using the method of melting in tapes overlap one after other, at only one transition of electron beam. The added layer (1) composed by powder adherent deposited on the surfaces A and B, by epoxy resins, the molten tape of the basic material (2), the solid tape of the basic material, not alloyed, influenced thermo-hardened, valuable only for the tempered materials (3), not influenced materials (4), the FE path, which generates the alloying tapes on the surfaces A and B, with long FE impulses (5), are marked out in the method of tapes overlap one after other. On C-C section fig 3, one can observe the level of the overlap tapes ( $L_{sup}$ ), at a certain width ( $L_{HV}$ ), on a depth of the impressed tape ( $H_s$ ), determined by the step between the tapes ( $p$ ).

### 5. HARDENING BY ELECTRON BEAM

An important problem is the deposit of alloying powder on the surfaces, which must be hardened so that on melting it would not

be expelled by the electron beam.

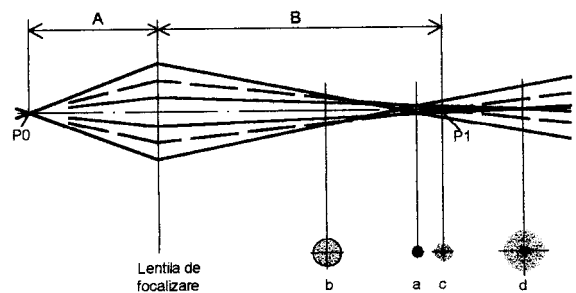
Between the methods used: sintering by electron beam of the powder directly on piece, deposit of powder in jet of plasma, the deposit of a mixture of powder with resin on piece was the most economical.

This method consists in making a mixture between the NESTAPOL 450 (N450) polyester resin make by Policolor (1 part) acetone (3 parts) and alloying powder. This mixture is deposited on piece in tapes after that the piece must be dried approximate 15 minutes.

### 6. THE ESTABLISH OF THE MAIN PROCESS PARAMETERS

a. The electron beam diameter,  $d_{FE}$ , is obtained function of focalization state corroborated with the work distance (fire). For alloying, a high focalization is necessary, fig 4, when the focal point is the surface of work piece.

The order respected for getting the right diameter of the electron beam is: first, one set the work distance to obtain the asked diameter (approximate), second, the focalization (that shown for EB in fig.4.a) is made by setting the coil current. A diameter with the desired accuracy and a uniform brightness of the electron beam spot are obtained.



**Fig.4. Form and positions diagram of the electron beams in a gun; a. strong focalization; b. under focalization; c. over focalization; d. beams leakage.**

b. The specific superficial power,  $q_{FE}$ , is calculated by the formula:

$$q_{FE} = P_{FE} / A_{FE} = 4I_{FE} \cdot U_a / \pi d_{FE}^2 \text{ [W/cm}^2\text{]} \quad (1)$$

where:  $I_{FE}$  = electron beam current, [A];  $U_a$  = acceleration power, [kV];  $d_{FE}$  = electron beam diameter, [cm].

c. The temperature at the piece surface,  $T_o$ , is approximated with good results by the formula:

$$T_{max} = \frac{0,75 \cdot q_{FE} \cdot \sqrt{a \cdot t}}{\lambda} \quad (2)$$

where:  $q_{FE}$  – relation (1);  $a$  – thermic diffusion quotient,  $[cm^2/s]$ ;  $t$  – heating time  $[s]$ ;  $\lambda$  – thermic conductivity quotient,  $[w/cm \text{ grad}]$ .

The material becomes melted when the electron beam power density reaches the  $10^7 w/cm^2$  value in less than 0,1 ... 0,2s and the melting temperature obtained is between 1600 ... 2600°C, depending on the kind of substance. The cooling velocity of the material can reach 10000°C/s, appreciatively.

## 7. RESERCH METHODS AND TOOLS USED

a. main material: stainless steel 10NiCr180 STAS 3583-64;

b. added material: powder P, NiCr 14 STAS 12390/85, made by IMNC Bucharest, similar to METCO 15E powder, made by SULZER METCO;

c. equipment for EB: 16 kW, 45 kV, made by IFIN – HH Magurele;

d. working environment: controlled atmosphere (inane);

e. alloying method: melting in tapes overlap one after other, at only one transition of EB, (item 5);

f. preparation of the alloying surface: scouring surfaces by brushing and pickling with organic solvents to remove any oxides, rust, oil, s.o.;

g. testing programm: with:

- variable parameters:  $L_I = 95 \div 105,2$  mm;  $I_{FE} = 22 \div 26,1$  mA;  $V_m = 0,66 \div 1,5$  m/mm;

- constant parameters:  $U_a = 45$  kV;  $I_F = 1110$  mA;  $\beta = 90^\circ$ ;  $L_{HV} = d_{FE} = 2,5$  mm;  $P_t = 10^{-6}$  torr; si  $P_i = 10^{-4}$  torr.

h. adjustment of overlapping of alloying tapes, fig.3, section C-C: is calculated by the formula:

$$L_{sup} = L_{HV} / 2 [mm] \quad (3)$$

and its measure is  $L_{sup} = 1,25$ mm, corresponding at the optimum for the best productivity and the most uniform hardness depth.

i. determination of main alloying technological characteristics: width of the alloyed tape  $L_{HV}$ , deepness of the alloyed

layer ( $H_s$ ), hardness of the alloyed layer HV, fig.3, section C-C, settled by the analyse of metallographic structure, after the procedure of preparing of sample according to STAS 4203-74 and the measurement of micro-toughness by the microscope according to the Vickers method with micro-charges STAS 7057-78.

## 8. RESULTS

Using the samples preparing actions, according with STAS 4203-74, with NEOPHOT 32 microscope endowed with PRACTICA photo set, and in conformity with 4203-74 STAS, the shape of a 51.2:1 size hardened patch was shown (fig.5 ÷ 7).

After alloying the maximum value of hardening was HV = 470 40gf/30, for the experiment  $i_4$  (fig.6), in  $a_0$  (the center of EB on the piece surface) and at maximum depth of  $H_s = 195$  mm for the experiment  $i_2$  (fig.5).

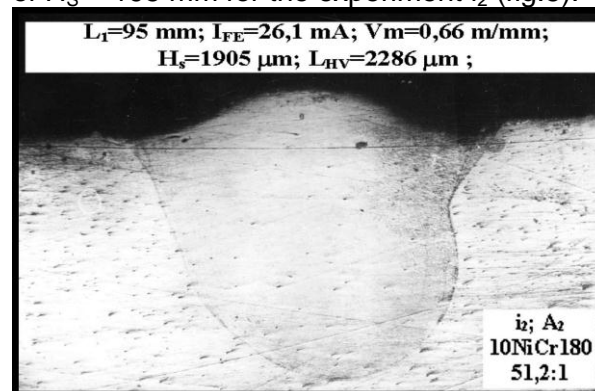


Fig.5. Alloyed – hardened patch for the experiment  $i = 2$ .

The alloyed elements contained in powder P – NiCr14 have enriched the melted layer in the alloyed patch, which allowing its improvement (hardening) by a very fast cooling of the matter mass.

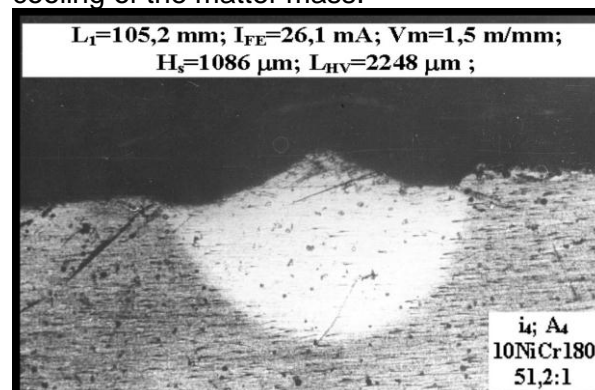
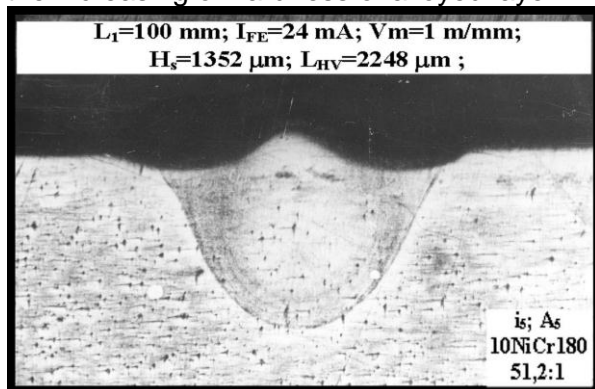


Fig.6. Alloyed – hardened patch for the experiment  $i = 4$ .

So, the carbon content in powder (0,4 – 0,95%), supplementary added in the alloying zone, performed the increase of perlite percent in the iron structure, improvement of the capacity of steel to harden and directly to the increasing of hardness of alloyed layer.



**Fig.7. Alloyed – hardened patch for the experiment i=5.**

Because overheat of the material during the melting process, the losing of carbon in the alloyed zone must be avoided.

Comparing the results shown in fig.5, where at 0.66m/mm velocity the hardening is HV= 380 40gf/30, with those shown in fig.6, where at Vm=1.5m/mm the hardening becomes HV= 470 40gf/30, one can observe the losing of carbon effect.

An additional increase of hardness HV = 470 40gf/30, obtained by alloying, on the surfaces A and B for the S. Fork, was performed after its rectification at HV = 900 – 1300 40 gf/30, by hardening with EB – HEB [1]. This process have led to a hardening without the melting of the material, heated at the temperature so that thereby the ferrite became austenite and through a rapid cooling, the carbon have not the time to precipitate away from solution. It remains inside the structure and creates a ferrite-sated solution, named martensite. This is possible because the layer enriched by the alloying elements (especially the carbon) can be improved-hardened, without the depreciation of the rectified surface.

## 9. CONCLUSIONS

1. The performed investigations display a high interest being a solution to replace the classic technology used till now, for S. Fork in the process of hardening of the mechanical stressed zone on a non-tempered material, by hardened disassembled boards, a very expensive and less reliable method, with a modern one, very economical, reliable which leads to the increase of life time of electro technical components of switch-over apparatus, with applications for other components too.
2. An additional increase of hardness HV = 470 40gf/30, obtained by alloying, was performed after its rectification of the surfaces A and B, at HV = 900 – 1300 40 gf/30, by hardening with FE – DFE [1]. This was possible because the layer enriched by the alloying elements (especially the carbon) can be improved-hardened, without the depreciation of the rectified surface.
3. From the multitude of electrotechnical and small mechanical pieces being in work, the S. Fork piece, was chosen, because it is the most representative concerning the technological problems issued in the hardening by electron beam process.
4. The solution of technological problems for S. Fork creates the bases for approach other types and dimensions of pieces such are: fasteners, check levers, catches, axes solenoids, palettes of turbines, surfaces of splinting tools, electric contacts, s.o.

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