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RESEARCHES ON THE SUPERFICIAL LAYERS MODIFIED OF THE VEHICLES PARTS AND COMPONENT PARTS, BY COMBINED PROCESSING IN LIQUID AND SOLID PHASE

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Abstract: *The paper presents the technological aspects of processing combined liquid and solid phase. Combined treatment goal is to get parts and automotive components by surface modified. Technological aspects analyzed include: the technological principle, experimental process flow analysis, interpretation of preliminary results. Novelty consists in obtaining superficial hardened layers of the vehicles parts by the implementation of the processing technologies combined liquid and solid having the following main phases:*
Phase 1 –superficial micro-alloying directly in the liquid phase, achieved by the interaction of the liquid steel with the layers deposited on the mould walls. The successive layers deposited on the mould walls have been obtained using a paste having as base the hardening mixture with the composition of 40% metallic powders and 60% carburizing powders;
Phase 2 –hardening thermal processing id made in an induction heating installation using treatment cycle-diagrams previously established depending on the base material of the vehicle part and on the composition and structure of the superficial layers obtained following the superficial micro-alloying directly in the liquid.
Phase 3 – final heat treatment, using a variant depending on the chemical composition of the base material (vehicle part core), composition and structure of the superficial layers and the real stress and service conditions of the vehicle part.

Key words: *researches, superficial layers, combined processing.*

1. INTRODUCTION

The technology has as objective the achievement of the hard superficial layers at the surface of the vehicles parts and component parts with a view to increasing the performances and the reliability of these ones using a new technology. Having a strong physical-chemical stability and high mechanical resistance to shocks, the micro-alloyed and hardened superficial layers represent the optimum solution that permits the increase of the durability of the component parts for auto-vehicles. The proposed technology presents a degree of novelty and complexity that consists in the followings:

- in the first step the micro-alloying of the superficial layers of the auto-vehicles parts is achieved directly in the liquid phase. The hardening mixture is in the form of a paste constituted by 40% metallic powder (nickel, chromium, vanadium) and 60% carburizing powders (charcoal, barium carbonate, coke, calcium carbonate, sodium carbonate, a binder) [5].
- in the second step the final hardening heat processing is achieved by induction, two physical-chemical phenomenon taking place simultaneously: martensitic hardening and formation of the hard chemical compounds in the superficial layer [10];
- in the third step the final heat treatment is achieved in several variants depending on the chemical composition of the base material, the composition of the superficial layers and the conditions of stress and service of the vehicles parts;
- the complexity results from the correlation of the results obtained in the three steps conforming to the input data of the process (chemical composition of the base steel, chemical composition of the micro-alloying and hardening paste) and the output data of the process (mechanical and structural characteristics obtained using the proposed technology comparing to those of the vehicles parts obtained by the classic technological variants) [3, 8].

2. THE PRINCIPLE OF TECHNOLOGICAL PROCESS

Combined treatment technology involves successive stages in the base material in different states of aggregation (Fig. 1). The principle of the technological processing based on the combined liquid and solid phase consists in:

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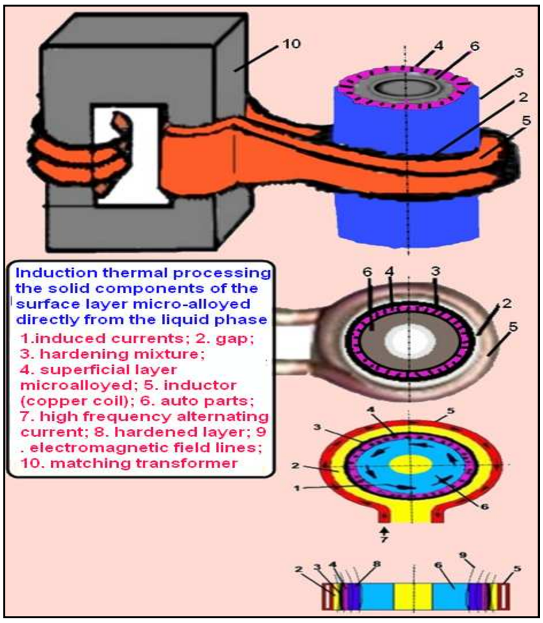

Fig. 1. The principle of technological process.

- Superficial micro-alloying directly in the liquid phase; microalierea involves the use of micro-alloyed paste as the main activator of the process.
- Induction thermal processing of micro-alloyed piece covered with mixed hardening; the mixture meets an active role in both the hardening process and in the microalloyed.
- Final heat treatment is carried out in four variants depending on the size and importance of auto parts.

3. TECHNOLOGICAL FLOW EXPERIMENTAL

Making preliminary experiments required the development of a flow sheet incorporating main phases. Regarded as a preliminary technology, flow comprises 12 phases (Fig. 2).

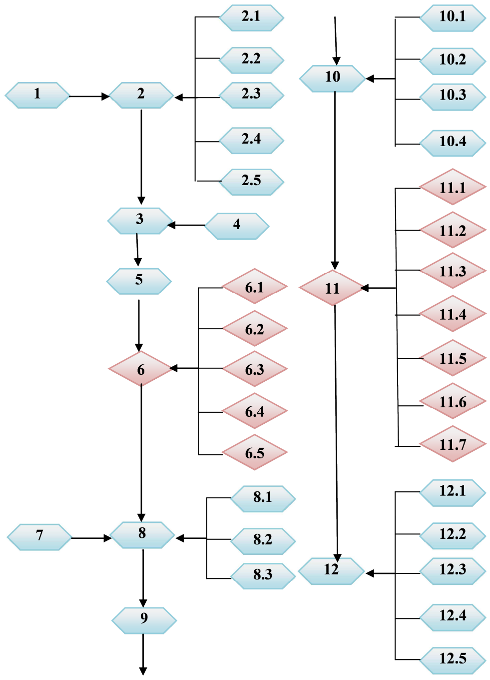

Fig.2. Scheme of the technological flow.

Table 1

The chemical composition of paste microalloyed PM

Symbol paste micro-alloyed	Composition paste microalloyed, %								
	Metal powders 40%			Carburizing powder 60%					
	Ni	Cr	V	Charcoal	$BaCO_3$	Cocs	$CaCO_3$	Na_2CO_3	Binder
PM	14	14	12	35	5	15	2	2	1

1. Preparation paste microalloyed PM: metal powders 40% + carburizing powder 60%.

Microalloyed paste is the main activator of microalloyed process (Table 1).

2. Preparation of the mold includes the following operations:
   2.1. Chemical and mechanical cleaning;
   2.2. Ventilated air drying;
   2.3. Deposition paste microalloyed PM;
   2.5. Preheating.
3. Elaboration of the base material is carried out in an induction furnace.

   Chemical composition: C < 0.3%, S < 0.02%, Si = max.1%, Mn = max.0.45%.
4. Casting and micro-alloying liquid phase

   The contact between the liquid steel and microalloyed paste elements diffusion occurs. Diffusion increases the microalloyed.

   $T_{casting}$= 1 550–1 600 °C;
   $V_{casting}$ = 0.2–2 kg/s;
   $t_{casting}$ = 2–60 s.
5. Preliminary machining: finishing lathering the superficial layer.

   turning depth: a_p = 0.05–0.40 mm;
   feed rate: fr = 0.05–0.10 mm/rot.
6. Control of the superficial layer
   6.1. Control macroscopic;
   6.2. Control metallographic structure;
   6.3. Control surface layer chemically;
   6.4. Chemically control the depth of 0.2 mm from the surface;
   6.5. Control surface layer hardness.
7. Preparation of the mixture of hardened AD (Table 2).

   The mixture is heated by induction hardening. The mixture becomes active in the process of micro-alloyed and hardening process.
8. Deposition of the mixture of hardened on the surface of the piece
   8.1. Surface cleaning;
   8.2. Deposit AD;
   8.3. Ventilated air drying

Table 2

The chemical composition of the mixture of hardened AD

Symbol paste micro-alloyed	Composition paste microalloyed, %								
	Metal powders 40%			Carburizing powder 60%					
	Ni	Cr	V	Charcoal	$BaCO_3$	Cocs	$CaCO_3$	Na_2CO_3	Binder
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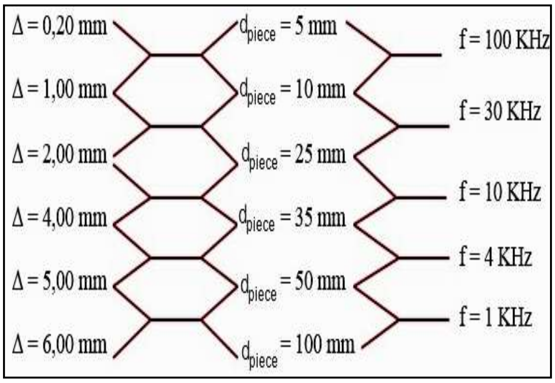

Fig. 3. Heated layer depth.

9. Induction thermal processing.

Induction processing is carried out in a spiral system, relatively simple in terms of construction. In general, the induction heating process characterized by the following nine sizes:

9.1. Heating temperature, T = 950–1050 ºC;

9.2. Diameter of workpiece, d =15–35 mm (r = 7.5–17.5 mm);

9.3. Heated layer depth respectively the depth of penetration of heat, Δ (mm), Fig. 3;

9.4. The depth of penetration of the electromagnetic field, respectively the induced current, δ (mm);

δ = 5.50 mm → d_{piece} = max. 50 mm → f =10 kHz;
δ = 1.75 mm → d_{piece} = max. 20 mm → f =100 kHz;
δ = 0.55 mm → d_{piece} =max. 15 mm → f =1 000 kHz.

9.5. Depth of hardening, ε (mm), Table 3.

9.6. The frequency (Fig. 4);

9.7. Specific power at the workpiece surface, P_{sp} (Fig. 5);

9.8. Heating time: $t_{heating}$ = 2–5 s;

9.9. Hold time: $t_{maintain}$ = 2–5 min.

Induction thermal treatment carried out in the experiments is characterized by the following values:

- T = 1 000–1 050°C;
- $t_{heating}$ = 2–5 s;
- hold time = 2–5 min;
- diameter: max. 35 mm;
- optimum frequency, f_{optim} = 10 kHz;
- specific power to the piece surface: Psp = 1 kW/cm^2;
- output power of the generator: 20 kW;
- current: 700 A;
- voltage: 20 – 30V.

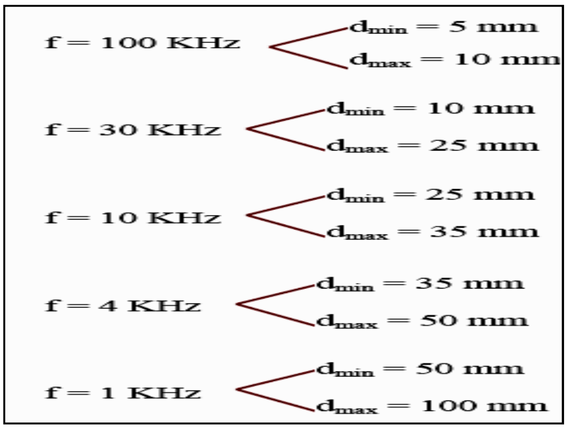

Fig. 4. The frequency.

Table 3

Depth of hardening

Depth of hardening ε (mm)	Heated layer depth Δ (mm)	Workpiece diameter *d* (mm)	The frequency *f* (kHz)
0.40–1.20	0.20–1.00	5–10	100
1.50–2.20	1.00–2.00	10–25	10
3.00–4.00	2.00–3.00	25–50	3
5.00–7.00	4.00–5.00	50–100	1

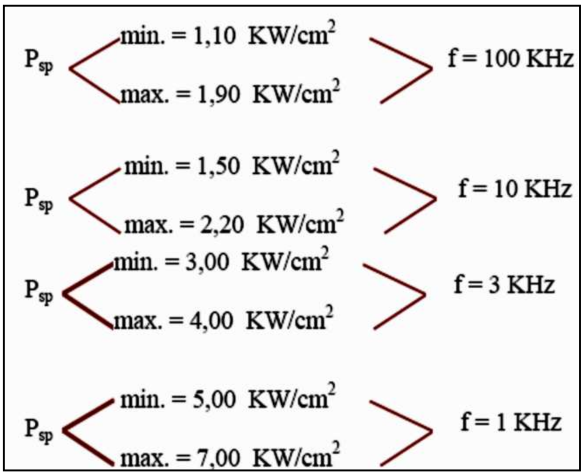

Fig. 5. Specific power to workpiece surface.

10. Final heat treatment

The final heat treatment 4 variants depending on the dimensional characteristics and importance of auto parts.

10.1. Variant A – direct hardening CD + low tempering RJ (it is applied to the vehicle parts of reduced importance that have to present especially high values of the superficial hardness, Fig. 6);

10.2. Variant B – accentuated cooling + layer simple hardening CS + low tempering RJ (it is applied in the case of the vehicle parts that have deformations, renouncing at the direct hardening. The parts are accelerated cooled in ventilated air and re-heated at 800÷840°C, in order to achieve the layer simple hardening, Fig. 7);

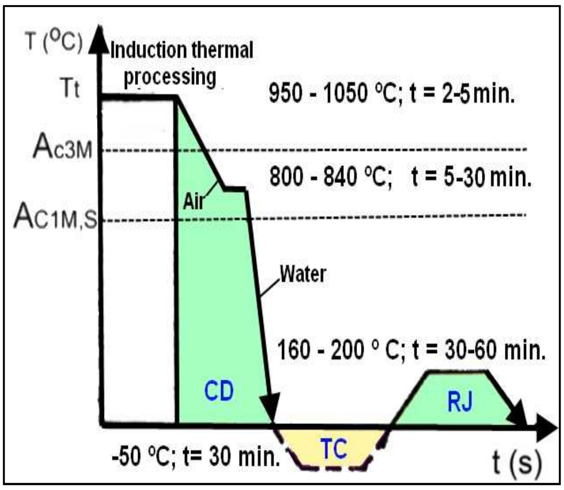

Fig. 6. A – direct hardening CD + low tempering RJ.

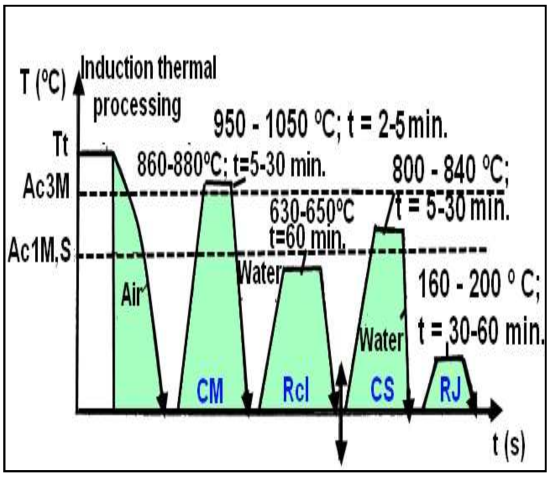

Fig. 7. B – accentuated cooling + layer simple hardening CS + low tempering RJ.

10.3. Variant C – accentuated cooling + intermediary sub-critical annealing RcI + layer simple hardening CS + low tempering RJ (it is applied in the case of the vehicle parts that need machining by cutting after treatment. Between carburizing and layer simple hardening a sub-critical intermediary annealing is introduced, at 630÷680°C, Fig. 8);

10.4. Variant D – double hardening with intermediary annealing (it is applied to the vehicles parts manufactured of medium alloyed steels superficially hardened for the improvement of the superficial layer performances, Fig. 9) [7, 9].

11. Control of the layer

Phase Control technology layer is certifying the quality of parts treated by the proposed technology on the following: hardness, fragility, thickness, metallographic structure, grain size, inclusions and specific adhesion.

11.1. Hardness control
- average of the hardness of the superficial layer: 60 HRC;

11.2. Control fragility
- does not present cracks in the proximity of a trace obtained by pressing a pyramidal diamond tip with a force of 100 daN [8];

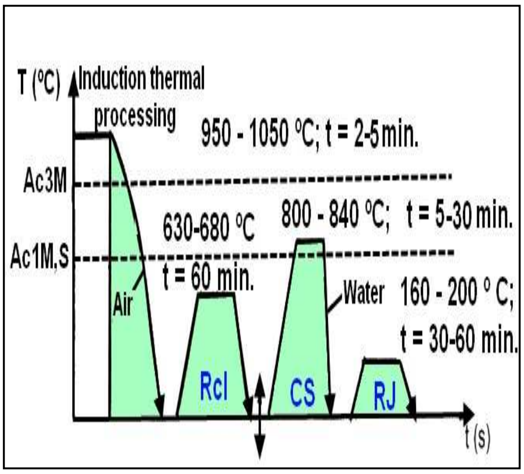

Fig.8. C – accentuated cooling + intermediary sub-critical annealing RcI + layer simple hardening CS + low tempering RJ.

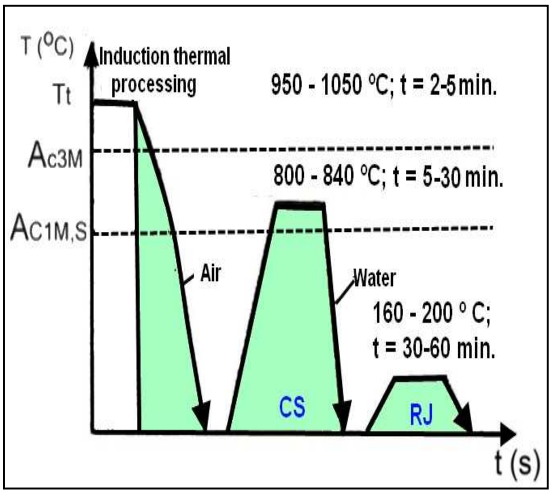

Fig. 9. D – double hardening with intermediary annealing.

11.3. Control surface layer thickness
- ε_u – useful depth carbide layer = the depth of the layer in which the carbon concentration is less than 0.40%; values of ε_u are based on the carbon concentration values determined by the depth of the step in accordance with the graphs of variation in the concentration of carbon in the depth of the layer, ε_u = min. 2.10 mm;
- ε_d – hardened depth = depth to a minimum hardness of 600 HV (~ 54 HRC), ε_d = min. 0.60 mm; values of ε_d are based on the average measurements of hardness layer depth in increments and in accordance with the charts of the depth variation of hardness carbide layer and microalloyed;
- ε_a – depth austenitising = distance from the workpiece surface to the point where the end of the heating temperature is set to T_a = 800 ºC; ε_a is determined by simulation to give T = 950 ºC→ ε_a= 2.111 mm, and for T = 1 050 ºC → ε_a= 2.614 mm;
- ε – hardening depth determined by empirical relationship ε = (0.05–0.10) d (mm); and the piece diameter of 35 mm is considered ε = 3 mm;

11.4. Control metallographic structure
- Structure preponderantly martensitic + complex carbides;

11.5. Control granulation
- fine granulation in the superficial layer; grain size index on the piece surface: 9, 10, 11 (Table 4).

11.6. Control inclusions

- reduced number of inclusions in the surface layer: p = max. 2 → A – sulfates = 0 ÷1; B – oxides linear = 1 (L_{max} = 5.5 µm) ÷ 2 (L_{max} = 11 µm; number of Inclusion = 4, total length = 44 µm), C

Table 4

Index of grain size

Index of grain size, *G*	Number of grains m, pe mm²			Grain average diameter, d_m, mm	Grain mean area *a*, mm² ×10⁻³
	Face value	Limit values			
		on	to		
9	4096	3072	6144	0.0156	0.244
10	8192	6144	12288	0.0110	0.122
11	16384	12288	24576	0.0078	0.061

– silicates = 0÷1; D – globular oxides = 1÷2 (D = 11 μm, standard image area = 95 μm^2);

11.7. Control specific adherence

$Q = F/A$; F= pressure, N;

A= surface area, mm^2.

Hard metal jointing: q > 170 N/mm^2.

12. Delivery of finished parts

Delivery is the last phase of experimental flow that incorporates: elements of competitiveness, framing the concept of "green product", environmental profile of the product Implement the principle of total quality, need for recycling product throughout the life.

12.1. Elements of competitiveness:

- estimated production costs fall as cost matrix imposed on the EU market;
- characteristics similar to parts and components manufactured in the EU;
- after-sales service: warranty 12 months;
- strengthening the company by creating new jobs.

12.2. Framing pieces made in the concept of "green product" which involves framing manufacturer in the concept of "green supplier" [1].

12.3. Environmental profile of the product made by processing technology combined.

- identification of environmental impacts they generate auto parts and components manufactured by processing combined liquid and solid phase;
- determine for each impact identified critical stages of the life cycle [2];
- identification margins improve;
- evaluation of the advantages and disadvantages presented ways to improve;
- replacement high alloyed steels with low alloy steels to achieve auto parts and components using: combined processing in liquid and solid form; design changes to provide more strength comparable to the original material [6].

12.4. Implement the principle of total quality

- periodic certification of personnel;
- accreditation of testing laboratories.
- technical level accepted for processing plants combined liquid and solid phase.
- high standards: remediation, storage, collection, recovery, reuse and recycling.

12.5. Recycling the lifetime of the product (considered in the design and manufacturing technology product) [4].

- recycling the product development phase: evaluation system before recovery + plan recycling;
- recycling in the production phase Product recycling technologies + range using recycled materials;
- recycling operations phase parts and components manufactured by the proposed technology: recycling + reconditioned;
- recycling of scrap during product: dismantling + efficient methods of waste from disposal.

4. PRELIMINARY RESULTS

Preliminary experiments were performed according to the experiment. In the experiments, values of the main technological parameters were:

- T = 1 000–1 050 °C;
- $t_{heating}$ = 2–5 s;
- hold time = 2–5 min;
- diameter piece: max. 35 mm;
- optimum frequency, f_{optim} = 10 kHz;
- specific power to the piece surface:
  Psp = 1–1.50 kW/cm^2;
- output power of the generator: 20 kW;
- current: 700 A;
- voltage: 20–30V;
- heated layer depth: Δ = 2.00–4.00 mm;
- depth of penetration of the electromagnetic field:
  δ = 5.50 mm;

Values of technological parameters had a limited range of variation. These parameter values induced following levels:

- heated layer depth: Δ = 2.00–4.00 mm;
- depth of penetration of the electromagnetic field induced currents respectively: δ = 5.50 mm;
- the depth of hardening: ε = 2.00–3.00 mm.

Carrying out preliminary experiments using small values of technological parameters generated superficial layers with the following characteristics (Fig. 10):

- ε_u – useful depth carbide layer = min. 2.10 mm;
- ε_d – strong depth hardened = min. 0.60 mm;
- ε_a – depth austenitising = 2.111 mm la T = 950ºC;
- ε_a= 2.614 mm la T = 1050 ºC;
- ε – hardening depth = 3 mm.

Control of superficial layers revealed the following:

- hardness: average of the hardness of the superficial layer: 60 HRC;
- fragility: does not present cracks in the proximity of a trace obtained by pressing a pyramidal diamond tip with a force of 100 daN;
- metallographic structure: preponderantly martensitic + complex carbides without separation of carbon;
- granulation: fine granulation in the superficial layer – index of grain size on the surface of piece is: 9, 10, 11;
- inclusions: p = max. 2 (A – sulfates = 0 ÷1; B – oxides linear = 1 ÷ 2; C – silicates = 0÷1; D – globular oxides = 1÷2);
- specific adherence**:** q > 170 N/mm^2.

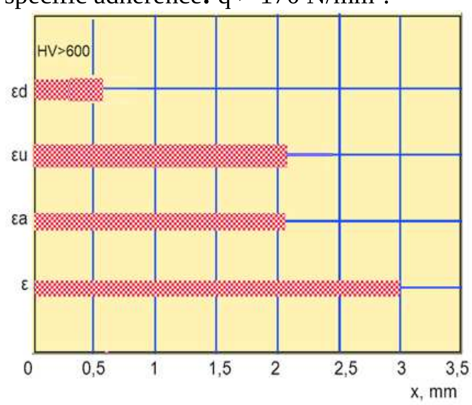

Fig. 10. Characteristics superficial layer.

Preliminary results highlight the quality layers. This is the main argument for further research to optimize and adapt the technology to the concrete conditions of production. Preliminary results support the viability of the process.

5. CONCLUSIONS

Superficial features pieces made in the preliminary experiments enroll within the acceptable level of quality demanded by the customer returns.

Optimization and adaptation processing methods combined actual production conditions will facilitate the implementation process.

In this context, in conditions of technology implementation, the main elements of competitiveness are:

- estimated production costs fall as cost matrix imposed on the EU market;
- characteristics similar to parts and components manufactured in the EU;
- after-sales-services consist of a warranty of 12 months;
- strengthening the company by creating new jobs.

Technology implementation the following aspects of conformity:

- making recital "green product" implies "green supplier";
- each type of piece produced by the proposed technology will have its own environmental profile;
- implementation of total quality principle on the technological flow;
- recycling throughout the product life (recycling considered in the design technology and product).

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