CONTRIBUTIONS ON RECONDITIONING BY ULTRASONIC FIELD SPRAY COATING METALLIZATION

Gheorghe Amza[1], Relu Fenechiu[2]
[1]Polytechnic University of Bucharest, amza@camis.pub.ro
[2]S.C. ENGEKO S.A. Iasi, mariana.fenechiu@gmail.com

ABSTRACT: The paper presents a novel reconditioning technology - reconditioning by ultrasonic field spray coating metallization, using the effects of propagation of ultrasound waves and of the ultra-acoustic field on the spray coating process and process of application of layers of application material onto worn surfaces. The paper presents a spray coating metallization gun with oxy-gas flame and wire, with ultrasonic activation of the wire made from the application material and a series of experimental results obtained on various couples of materials used in the construction of parts used in the automotive industry (crankshafts, camshafts, variable diameter shafts, CV shafts, etc.) The results of the measurements show an increase of the hardness of the resulting couple by 15-22% and of the resistance against corrosion by 18-30%.
KEYWORDS:metallization, spray coating, ultrasonic field.

1. INTRODUCTION

In most cases, repairs in the automotive industry are conducted by replacing worn parts/sub-assemblies with new ones, although a series of repair technologies is available by reconditioning the worn surfaces and restoring it to the same functional parameters, the costs being 40-60% lower as compared to the value of new parts / sub-assemblies. Replacing worn parts represents the simplest and yet most inefficient solution, considering the need of materials and energy characterizing mankind, both today and especially in the future.

Repairing certain important parts by reconditioning (crankshafts, camshafts, variable diameter shafts, cylinder heads, engine blocks, track rod ends, pivots, CV shafts, drive shafts, gears, etc.) comes with a series of benefits, the most important ones including:[1,2,3].

- significant savings in materials, as the only material used is the one used to load up the worn surface, following which the surface is processed to be restored to the functional sizes, which means much lower consumption of material as compared to the manufacture of a new part;
- significant savings in energy, as energy is only consumed with the operation of loading up the worn surface and not with all the operations associated with the technological process of making a new part;
- significant savings in labour, as the only labour put in is for the reconditioning operation, which is much less than the amount of labour put into obtaining a new part;
- significant savings in equipment and tools, as the equipment and tools required to obtain a new part are much more expensive than those required for restoring worn surfaces,
- obtaining parts with much better functional characteristics than a new part, as the possibility is allowed to increase wear resistance by 80-300%, fatigue resistance by 15-40% and corrosion resistance by 30-60%
- significant reduction in environmental pollution, as the polluting substances resulting from the reconditioning are much fewer and the quantities much smaller than in the case of manufacturing new parts.

However, with the reconditioning comes a series of disadvantages, the most notable ones including:

- the requirement of compatibility between the base material and the applied material in order to obtain the best possible adhesion of the applied layer onto the worn surface;

- the development of thermally processed areas where numerous irregularities may occur which may affect the lifespan of the reconditioned part;
- the lack of homogeneity of the properties and functional and technological characteristics of the applied layer and respectively of the whole reconditioned part;
- the necessity of a post-application thermal treatment which entails additional consumption of energy and additional costs.

Considering the disadvantages of the classic reconditioning procedure, the paper proposes a novel work technology - reconditioning by ultrasonic field spray coating metallization, a technology which leads to a reduction or even total removal of the disadvantages stated above.

A part of the disadvantages of the classic procedure was removed by using the hard-chroming procedure which leads to an increase of the hardness of the applied layer and respectively to an increase of the wear resistance by reducing the contact friction index, as shown in paper: *Relu FENECHIU and Cătălina AXINTE, "Increasing engine efficiency by reducing loss of energy by friction using hard-chroming" published in the Bulletin of the Iaşi Polytechnic Institute, Tome LXI(LXV), Fasc. 2, 2015.*

The most complicated problem that needs solving and on which depends the manner of influencing the ultrasonic field reconditioning process is the way in which ultrasound is introduced in the working area, which involves making special ultrasound systems which need to comply with a series of technological, mechanical and acoustic requirements.

2. THE ULTRASOUND SYSTEM USED IN EXPERIMENTS

For ultrasonic field spray coating metallization reconditioning, a spray coating metallization gun was built with oxy-gasflame and wire with the ultrasonic activation of the wire used as application material (Fig. 1). Electrode-wire 1 from the application material is pushed by rollers 2 and passes through the acoustic reflector 3, piezoceramic discs 4, acoustic radiant 6, nodal flange 7, coupling element 8, ultrasonic energy focusing piece 9, the active part of the ultrasound energy focusing piece 10 and reaches in oxy-acetylene flame 11 where it melts in the form of droplets 12. Through nozzle 14 the projector gas is introduced which projects the liquid droplets of application material onto the used surface of the parts to be reconditioned 16, forming a layer of application 15. The entire ultrasound system is thus calculated and designed so that across its length the particles vibrate in ultrasound after a variation given by diagram 20 and work in a regime of resonance.[11,12].

The ultrasound system is thus designed so as to allow obtaining important advantages owed to the manner of propagation of the ultrasound field and to the effect of propagating ultrasounds, the most important such advantages being:

- the acceleration of the diffusion process from the application material towards the base material and the easier formation of homogeneous binding between the materials of the couple;
- achieving a very fine spraying effect of the applied material and improving the process of transfer of the applied material onto the base material;
- avoiding the oxidation of particles of application material and avoiding the
- development of defects of non-metal inclusion type;
- accelerating the process of crystallization and solidification obtaining a fine granular structure with equiaxed grains in all three important areas of the couple: application material, demarcation line and support material;
- obtaining certain functional characteristics that are 30-300% better than in the case of a new part, at a cost of a reconditioned part which is 40-60% lower than in the case of a new part;
- increasing the durability of the reconditioned part 1.5-3 times as much as compared to that of a new part;

- substantial increase of the rate of application and productivity;
- eliminating the need to treat thermally after loading up;
- significant increase of the efficiency of the reconditioning process by spray coating;
- metallizationreducing the pollution of the work environment.

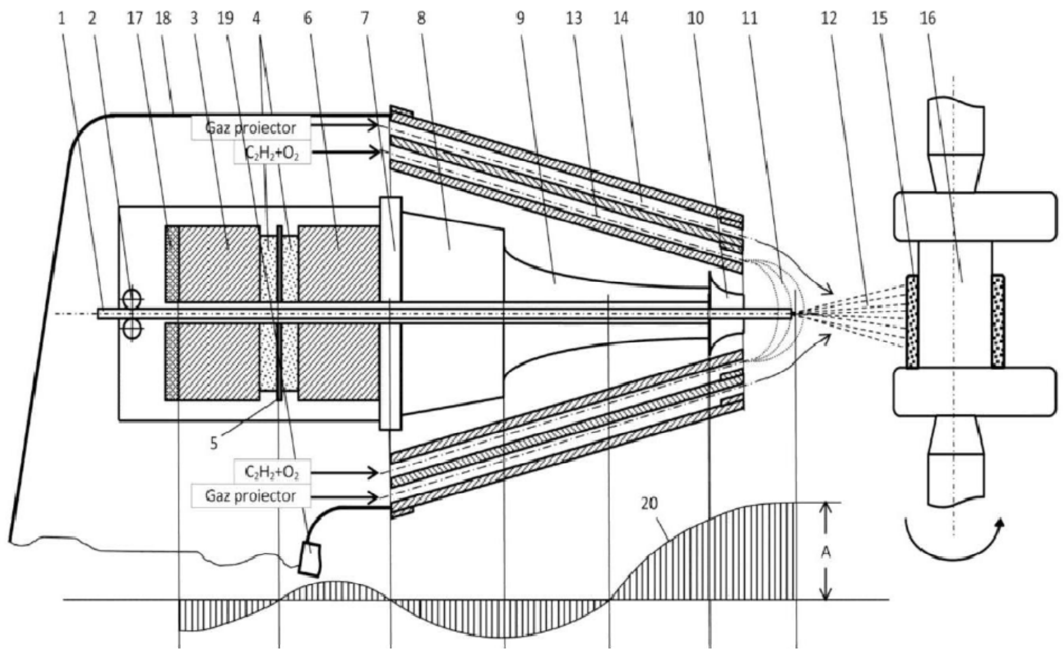

Figure 1. Theoretical scheme of an ultrasonic field metallization gun with flame and wire model MFS-US01

Legend of figure 1

1 - application material; 2 - drive rollers; 3 - acoustic reflector; 4 - piezoceramic discs; 5 - contact electrode; 6 - acoustic radiant; 7 - node flange; 8 - acoustic coupling; 9 - acoustic amplifier; 10 - active part of the sound focusing piece; 11 - oxy-acetylene torch; 12 - liquid particles of application material; 13 - nozzle for combustible gas; 14 - nozzle for projector gas; 15 - applied layer; 16 - part to be reconditioned; 17 - acoustic insulator; 18 - protective housing; 19 - drive butterfly flange; 20 - diagram showing variation in the amplitude of the particle speed across the length of the ultrasound system; A - degree of amplitude in the melt area

3. EXPERIMENTAL RESULTS

In order to establish the optimal technological process of reconditioning by spray coating metallization of parts typical for the automotive industry, a work method was established, as well as a set of experiments allowing a comparative analysis between the samples metallized by spray coating with and without ultrasound activation. The stages of the technological process were the same, executed in the same conditions, with the same parameters, except for the stages in which ultrasound was used (the stage of surface cleaning and the stage of actual metallization). The following work method was established and the following sequence of activities: [5,7]

- establishing the parameters of the spray coating metallization regime for the analyzed method (with oxy-gas flame and electrode-wire for the application material);
- the execution of the application in one layer, with various parameters of the regime of spray coating metallization with and without ultrasonic activation;
- the execution of application of material until obtaining the required thickness of applied material, as requested by the functional size;

- determining the functional properties of the couple resulting pursuant to the process of spray coating metallization with and without ultrasound activation;
- structural analyses in the distinct areas of the resulting couple: application material, around the demarcation line and support material;[10].
- evaluating the possibilities of increasing the productivity and the efficiency of the
- metallization process.

Table 1. Values of parameters of the metallization regime with oxy-gas flame and wire, without ultrasound activation[4,6]

Nr. crt.	Sample	Parameters of the regime of metallization without ultrasound activation												
		p_{C2H2} [bar]	p_{O2} [bar]	V_{O2}/V_{C2H2}	p_{gp} [bar]	L [mm]	α [º]	d [mm]	v_{av} [mm/s]	v_{dp} [mm/s]	Q_{O2} [m³/h]	Q_{C2H2} [m³/h]	Q_{gp} [m³/h]	No. of layers
1	Sample 1u	2,5	6,0	1,05	5,0	150	90	2,0	8,5	80	8,5	1,5	14,0	40
		3,5	8,0	1,05	5,5	150	90	2,0	9,5	90	10,5	2,0	16,0	50
		4,5	10,0	1,05	6,0	150	90	2,0	10,2	100	12,5	2,5	17,5	60
2	Sample 2u	2,0	5,0	1,08	4,5	120	75	2,0	5,5	65	8,0	1,0	12,0	40
		3,0	6,0	1,08	5,0	120	75	2,0	7,5	75	9,0	2,0	13,0	50
		4,0	8,0	1,08	6,0	120	75	2,0	9,3	85	10,0	2,8	14,0	60
3	Sample 3u	2,8	5,5	1,01	3,5	200	90	2,0	8,8	60	10,2	1,7	13,0	40
		3,8	7,5	1,01	4,5	200	90	2,0	9,8	80	12,2	2,4	15,0	60
		4,8	9,5	1,01	5,2	200	90	2,0	10,8	100	14,2	2,6	17,0	80

p_{C2H2} - pressure of combustible gas; p_{O2} - oxygen pressure; p_{gp} - pressure of compressed air used as projecting gas; V_{O2}/V_{C2H2} - volumetric ratio O_2/C_2H_2; L - spray distance; α - spray angle; v_{AV} - speed of advance of application material wire; v_{dp} - gun travel speed; Q_{O2} - oxygen flow; Q_{C2H2} - acetylene flow; Q_{gp} - projector gas flow; d - diameter of electrode wire.

Table 2. Value of parameters of the metallization regime with oxy-gas flame and wire, with ultrasound activation of the application material wire

Nr. crt.	Sample	Parameters of the regime of metallization in ultrasound field															
		p_{C2H2} [bar]	p_{O2} [bar]	p_{gp} [bar]	L [mm]	α [º]	d [mm]	v_{av} [mm/s]	v_{dp} [mm/s]	I_u [w/cm²]	f [kHz]	A [μm]	p_u [bar]	Q_{O2} [m³/h]	Q_{C2H2} [m³/h]	Q_{gp} [m³/h]	No. of layers
1	Sample 1u	2,5	6,0	5,0	150	90	2,0	8,5	50	5,6	22,0	41,5	1,2	8,5	1,5	14,5	40
		3,5	8,0	5,5	150	90	2,0	7,5	60	6,8	22,0	43,7	1,6	11,5	2,0	16,0	50
		4,5	10,0	6,0	150	90	2,0	10,2	70	7,5	22,0	59,6	1,9	12,5	2,5	17,5	60
2	Sample 2u	2,0	5,0	4,5	120	75	2,0	5,5	40	8,1	24,0	38,9	0,9	8,0	1,0	12,0	40
		3,0	6,0	5,0	120	75	2,0	7,5	45	9,2	24,0	47,2	1,7	9,0	2,0	13,0	50
		4,0	8,0	6,0	120	75	2,0	9,3	50	10,7	24,0	57,6	1,8	10,0	2,8	14,0	60
3	Sample 3u	2,8	5,5	3,5	200	90	2,0	8,8	55	10,5	25,0	56,4	1,9	10,2	1,7	13,0	40
		3,8	7,5	4,5	200	90	2,0	9,8	60	11,3	25,0	72,7	2,1	12,2	2,4	15,0	60
		4,8	9,5	5,2	200	90	2,0	10,8	65	11,9	25,0	81,6	2,5	14,2	2,6	17,0	80

p_{C2H2} - pressure of acetylene; p_{O2} - oxygen pressure; p_{gp} - pressure of projecting gas; L - spray distance; α - spray angle; v_{AV} - speed of advance of application material wire; v_{dp}-gun travel speed; Q_{O2} - oxygen flow; Q_{C2H2} - acetylene flow; Q_{gp} - projector gas flow; I_U - ultrasound intensity; f - ultrasound frequency; A - amplitude of longitudinal ultrasound oscillations; p_U - ultrasound pressure; d - diameter of electrode wire

The values of parameters of the spray coating metallization process with oxy-gas flame and wire without ultrasound activation are presented in table 1, while table 2 shows the values for the spray coating metallization process with ultrasound activation of the electrode-wire of application material.

Spray coating metallization was performed on a couple of materials specific to a crankshaft used in automotive manufacturing: the base (support) material - alloy steel of type X30NiMoVCr11 the chemical composition of which is presented in table 3 and application material - STELLITE 12AWS,W, the chemical composition is presented in table 5. [1,2,4]

The application of the application material was performed in layers of 0.5 - 3.0 mm, depending on the degree of wear that can develop in the automotive parts that can be reconditioned. During the application was monitored the temperature of the support material by infrared thermal imaging because when temperatures are reached in the range 473-523K, the metallization process is interrupted for 2-3 minutes and then it is resumed until reaching the thickness required by the function of the part.

Table 3. Chemical composition of the support material used in experiments[3]

	Content and alloy element [%]					
Base (support) material X30NiMoVCr11	C	Ni	Cr	Mo		Si
	0,20...0,33	3,75...4,0	1,11...1,13	0,45...0,35		0,25...0,35
	Mn	V	P	S		Cu
	0.30...0,45	≤0,10	≤0,01	≤0,005		0,08
	Nb	Tn	Ti	B		W
	0,001	0,001	0,002	0,001		0,02
	Cn	Ce	Al	N	Fe	H[ppm]
	0,002	**0,006**	**0,017**	**0,001**	**Rest**	**2,0**

Table 4. Chemical composition of the application material STELLITE 12 AWS, W

	Components and chemical composition [%]				
Application material STELLITE 12AWS$_1$W	C	Cr	Si	W	Fe
	1,430	24,60	1,520	8,30	2,10
	Ni	Mn	mo	B	P
	1,980	0,270	0,670	0,005	0,004
	S	O_2	Co	-	-
	0,004	0,005	Rest	-	-

The application of the application material was performed in layers of 0.5 - 3.0 mm, depending on the degree of wear that can develop in the automotive parts that can be reconditioned. During the application was monitored the temperature of the support material by infrared thermal imaging because when temperatures are reached in the range 473-523K, the metallization process is interrupted for 2-3 minutes and then it is resumed until reaching the thickness required by the function of the part.

4. CONCLUSIONS

- The experiment results obtained and measurements performed in the case of reconditioning by spray coating metallization with and without ultrasound activation lead to some interesting conclusions:
- in the case of spray coating metallization in ultrasonic field was found a higher variation of the content of W and Fe around the demarcation line as compared to the metallization without ultrasound activation;
- the adhesion of the layer of application material to the base material is much better in the case of ultrasound activation than in the case of metallization without ultrasound activation;

- in all cases of spray coating metallization in ultrasound field was found an increase of hardness by 12-18% in the close vicinity of the demarcation line and by 15-22% in the applied layer;
- the size of the grains of the resulted structure depends on the size of amplitude of ultrasound oscillations (the size of the grains decreases as frequency increases), with an optimal value for each couple of materials;
- upon spray coating metallization in ultrasound field we could not see any cracks or fissures in the base material or around the demarcation line or in the application material;
- upon the development of pores and inclusions, the method is very important of introducing ultrasound in the spray coating metallization process, as well as the amplitude and frequency of ultrasound oscillations;
- in all spray coating metallization cases with ultrasound activation of the process, adhesion to traction forces increases by 15-29%, while adhesion to shear forces by 9-18%.

5. REFERENCES

1. Amza, Gh.,*Contribution regarding metal pieces recycling by oxi-gas flame metallization using ultrasonic activation of the base material* – Section Name 18, Recycling of vastes (metallurgical mechanical, chemical of a power plant after mining and mineral processing activities food industry), 15 th International SGEM Geoconference, Albena – Bulgaria, 22 – 25 iunie, (2015).
2. Amza, Gh.,*Ecotehnologie şi dezvoltare durabilă*, Editura Printech, Bucureşti (2009).
3. Amza, Gh.,*Tratat de Tehnologia Materialelor*, Editura Academiei României, Bucureşti, (2002).
4. Amza, Gh., *Ultrasunetele – aplicații active*, Editura AGIR, Bucureşti, (2009).
5. Amza, Gh.,ș.a,*Theoretical and Experimental Contributions on sprazing metallisation on ultrasonic field,* WSEAS, (EFETE), Bucharest, (2010).
6. Albulescu, R.,*Teza de doctorat- Contribuții teoretice și experimentale privind placarea în câmp ultrasonic a capetelor de erupție folosite în industria petrolieră*, (2014).
7. Bansevicius, R.,*Ultrasonic Motors*, Latvia, (1994).
8. Dumitru, G.M.,*Recondiționarea pieselor*, Editura Bren, Bucureşti, (2010).
9. Relu,F.,Axinte, Cătălina,*Increasing engine efficiency by reducing loss of energy by friction using hard-chroming* published in the Bulletin of the Iaşi Polytechnic Institute, Tome LXI(LXV), Fasc. 2, (2015).
10. Jefferson, T.B.,ș.a.,*Metals and how to weld them,* Second Edition, (2002).
11. Karlssonf, L.,*Welding of dissimilar metals*, Welding in the world, vol. 36, (1995).
12. Tzan, H.S., Fn, H.Q.,*A study of segmentation of distributed piezoelectric sensors and activators,* part. I: theoretical analysis, Journal of Sound Vibration 172, 247 – 57, (1994).
13. Uchida, M.,*Advanced Materials Composite*, Ed. Kogyo Chosakai Ttd – Tokio, Japan, (1996).