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REDUCTION RATE OF REMANENT STRESS IN THERMAL SPRAYING DEPOSITIONS BY SHOT PEENING

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ABSTRACT

Thermal electric-arc spraying coatings are widely utilized both to get new parts ant to repair the used ones. Just like with the other thermal spraying procedures, the other thermal spraying procedures, the thickness of these coatings is limited by the level of the internal stresses developed in the depositions. The paper presents an indirect method of measuring these internal stresses consisting in metal spraying the surface of a steel strip and then measuring the deflection of the respective strip curvature. The second part of the paper shows a method of reducing remanent stresses by making use of spherical steel shot peening.

KEYWORDS: Remanent stress, Shot peening, Thermal spraying

1. Measurement of remanent stress in the depositions carried out by thermal spraying

Remanent stress is stress existing in a solid body in absence of exterior stress [1] [2]. As a rule, remanent stress is generated in three ways: thermal stress (as a result of non-uniform extension or contraction because of differences in temperature, cross section and volume); structural stress (produced by suppressing volume changes specific to heating or cooling transformations); operational stress (introduced as a result of mechanical action during casting, deformation, welding, cutting).

Remanent stress falls under three categories: macroscopic, microscopic and submicroscopic or reticular

The coating technology by thermal electric-arc spraying is now widely utilized to repair the used parts or to become preventively coated the new parts in order to increase their reliability. Just like with other thermal spraying procedures, the deposit thickness is limited to the level of the internal stresses developed in the deposition.

It is well-known that the most defects emerging at the parts coated by thermal spraying appear when exceeding the accepted values of the deposit remanent stresses during the spraying process, mechanical working or exploitation.

A simple method for determining the remanent stress, method which might be used in any thermal spraying workshop, is that consisting in performing a deposition on a steel strip and then measuring the amount of deflection of the respective strip.

The condition that the sample must meet is to be elastic so as not to appear remanent deformations which could distort the results of the measurements, and concerning its section and length, respectively, the elasticity is needed to allow elastic deformations measurable by ordinary control means (micrometer, comparator).

Knowing the relation existing between stress (σ) and deformation (ε), σ=Eε, and between specific deformation (y) and radius of curvature (ρ), we may write [3]:

$$\varepsilon = \frac{y}{\rho}$$

where: $\sigma = E\frac{y}{\rho}; \rho = \frac{l^2 + 4f^2}{8f}; y = \frac{g}{2}$

That leads to: $\sigma = 4E\frac{\rho f}{l^2 + 4f^2}$.

Simplifying and admitting an error of less than 1%, the formula becomes [4]:

$$\sigma = 133{,}75 f \left[N / mm^2 \right].$$

The spraying parameters conditioning the heat amount of the melt particles influence directly the remanent stresses [6] [7]. Therefore, the small particles will lose more heat during flying and thus, the heat transfer at the base surface level will be less.

The diminution of transferred heat amount entails the reduction of stresses in the layer.

The increase of the air pressure enhances the fineness of the particles what leads to decrease the remanent stress. The increase of the voltage determines the increase of the particle temperature and consequently, this leads to high stresses. The spraying distance is inversely proportional to the temperature at which the particles reach the work piece, and therefore also to the stresses induced in the layer.

In addition to the remanent stresses developed during the thermal spraying, as a result of the reasons presented above, there are also another category of stresses induced due to the phase changes during the solidification and cooling of the deposition.

The volume modifications associated to the phase transformations which occur at high temperature, tend to be equilibrated by tensions causing plastic deformations.

The present method is exact and efficient, being able to be applied in any specialized metal spraying workshop, and allows, when the spraying conditions are different from those under which the tests were made, to perform spraying tests and determine optimum working parameters. It is also possible to use for spraying some other materials that have not been tested or have uncertain composition.

First, the initial deflection was measured by means of a comparator device, and then the first deposit was sprayed up to 0.1 mm in thickness. The amount of deflection was measured again and then other depositions of 0.1 mm in thickness were performed, always making measurements of deflection for each one. The data obtained were used to trace diagrams and to determine the calculation formula for the function σ=ks.

The temperatures of the work pieces were measured making use of a precision pyrometer – HPA Carl Zeiss Yena type ranging from 0^{o}C to 900^{o}C and owning a measurement precision of 1 %.

Each test was made on there samples sprayed under identical conditions with a TEROSPRAY-E3 metal spraying plant.

Till now, there were tested the following categories of materials: carbon steel, alloy steel, mild non-ferrous materials (aluminium, copper, brass), hard non-ferrous materials (bronze, Cu-Ni alloys). It was analyzed the influence of the following factors on the amount of the remanent stresses existing in the deposits: voltage (V), air pressure (bar), spraying distance (mm), work piece temperature (^{o}C).

The curve charted after performing the measurements on strip-type samples, while the deposit thickness increases, presents a straight line with a high slope for the first 0.1 mm deposits followed by another straight line of smaller slope for the deposits of up to a 0.8….1.0 mm thickness. It found that the remanent stresses increase uniformly together with the increase of the deposit thickness (fig.1).

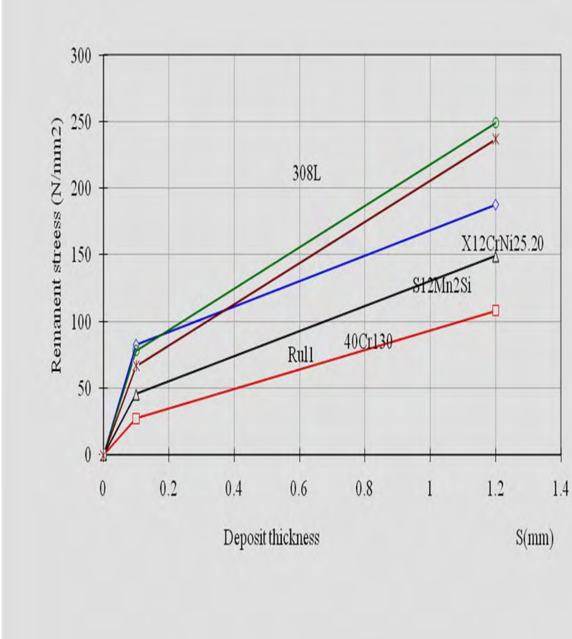

Fig.1. *Diagram of remanent stress at the base of deposition –deposit thickness obtained by electric arc for the tested materials.*

2. Reduction of remenent stresses in the depositions carried out by thermal spraying

Depending on the material and the deposit thickness, the methodology establishes the technological parameters of shot peening hardening so as to make sure the reproducibility of the testing results and the diminution of the remanent stresses of 30 %, at least.

To reduce the remanent stresses in the coatings obtained by thermal spraying it was used the stress relieving method by shot peening.

Shot peening is a superficial hardening procedure applied to metallic workpiece surface.

This is performed by bumping spherical metallic shots upon work piece surface, these shots being highly speed ejected by some turbo blades or an air-compressed jet.

After performing the depositions by metallizing for the materials indicated above, there were measured for each sample the initial and final deflections, the total deposition thickness as well as the tension stress at the base of the deposition according the final deflection.

The duration of hardening between two measurements is chosen depending on the material, respectively on its capability to accumulate compressive stresses during shot bumping.

Based on those measurements the diagrams σ-t_a, meaning the variation of remanent stress in relation to hardening duration were charted (fig.2).

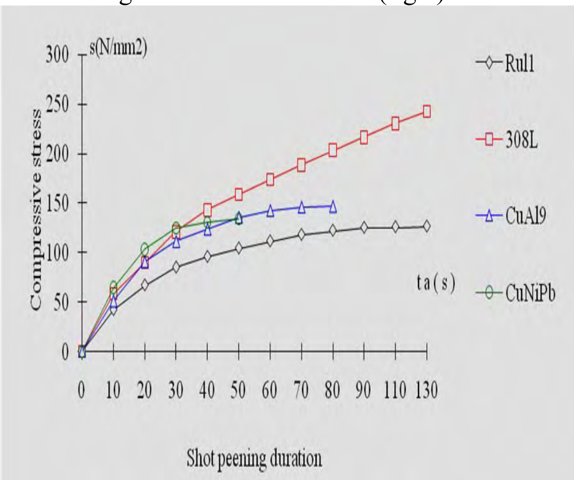

Fig. 2. *The variation of remanent stress in relation to hardening duration.*

The shot peened surfaces improve their appearance becoming smoother, this feature being very important for these surfaces which are not going to be machined after that.

It was also determined the diagram depicting the deposit thickness reduction according to the shot peening duration (fig.3); in this diagram can be noticed the time when the saturation phenomenon appears (continuing to bump shots on surface doesn’t produce significant compressing stresses in the deposit anymore).

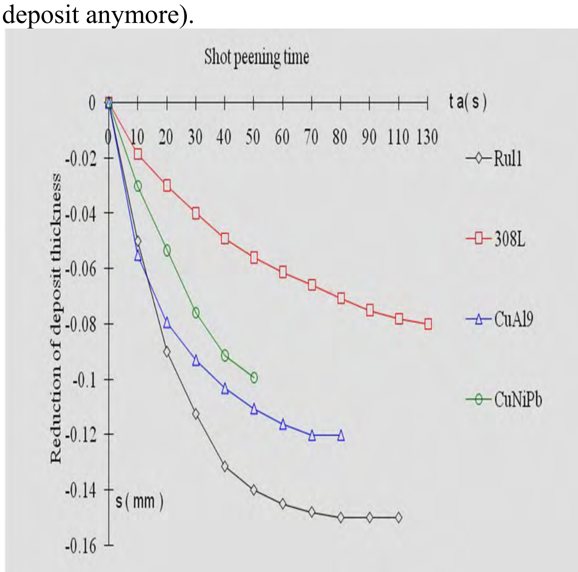

Fig.3. *The diagram depicting the deposit thickness reduction according to the peening duration.*

There were also determined the specific shot peening durations (t_a) what represents the shot peening duration per surface unit (cm^2). This unit is needed to make comparison among different materials and to apply stress relieving by hardening to real workpieces.

3. Reduction rate of remanent stress and compaction rate of thermally sprayed deposit

The mechanical treatment of hardening by shot peening of the metallic depositions surfaces obtained by thermal spraying entails the modification of some of their physical-mechanical properties, such as: porosity reduction, mass density increase, remanent stress reduction by inducing compressive stresses. These changes have as effect the following: increase of corrosion resistance of the coatings (stainless steels and non-ferrous materials) due to the decrease of permeability, mass density increase, deposition hardness increase, fatigue strength increase.

Logically, these modifications influence the tribological properties of the antifriction materials applied by metal spraying.

The values of stress relieving duration and of remanent stress were determined for each tested material.

These values were used to chart two diagrams.

The first diagram represents the variation of the shot peening duration for tested materials in relation to the stress relieving percentage (fig.4).

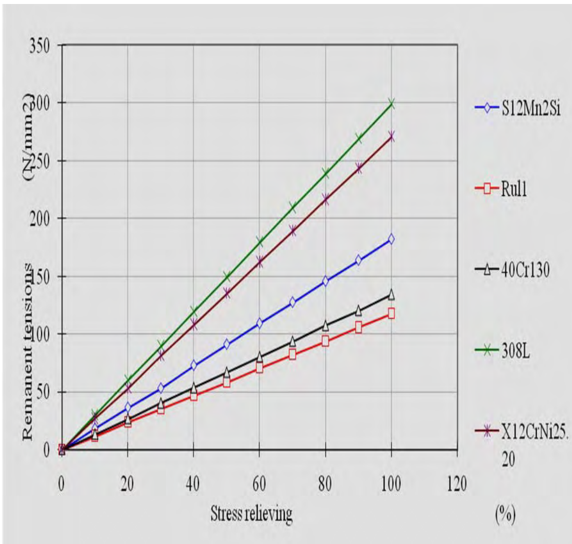

Fig.4. *Variation of remanent stress to stress relieving percentage.*

The second diagram depiets the variation of the remanent stress for each tested material in relation to the stress relieving percentage (fig.5).

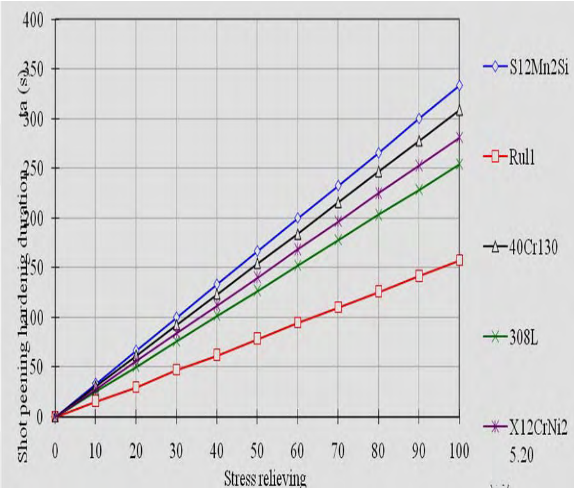

Fig.5. *Variation of shot peening hardening duration to stress relieving percentage.*

In the two diagrams, the variation of the shot peening duration and of the remanent stress to stress relieving percentage is linear, the differentiation being made by the chart slope given by the hardening level of the depositions. The two diagrams are useful when, for a coating material, we need to know exactly the shot peening duration required to reach a certain stress relieving degree.

From the analysis of the diagrams [4], $\sigma = f_1(t_a)$ and $S = f_2(t_a)$, we can define the parameters K_1 and K_2 [5] for the two zones of proportionality, where:

K_1- reduction rate of remanent stress in the deposit coated by electric-arc spraying (N/mm^2s);

K_2 – reduction rate of deposit thickness coated by electric-arc spraying (N/mm);

S_d – deposit thickness (mm);

S_{rg}- thickness reduction (mm);

t_d – coating duration (s);

t_e- shot peening hardening duration (s);

p_d- stress relieving percentage (%).

$$tg\alpha = K_1 = \frac{\sigma_t}{t_d}$$

$$tg\beta = K_2 = \frac{S_{rg}}{t_d}$$

$$tg\gamma = K_3 = \frac{\sigma_t}{S_d}$$

4. Conclusions

Concluding, we may say that for these coating materials the shot peening represents a technological possibility to increase the operating durability of the depositions performed by electric-arc spraying.

The researches undertaken so far entitle us to extend the investigations, both by lab experiments and on real operating equipment, to another pseudo-alloys and alloys coated by thermal spraying, too.

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