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# RESEARCH ON ABRASIVE WEAR BEHAVIOUR OF LASER CLADDING LAYERS WITH ALUMINUM BRONZE POWDERS

**Simona BOICIUC**
"Dunarea de Jos" University of Galati, Romania
e-mail: simonaboiciuc@yahoo.com

## ABSTRACT

*The paper presents the wear behaviour on rotating disk with abrasive paper of laser cladding layers with aluminum bronze powders compared with steel samples and aluminum bronze classically quenched. The hardness and wear mass variation were monitored.*

KEYWORDS: laser cladding, aluminum bronzes, powder, injection

## 1. Introduction

With the rapid growth of laser applications and the reduced cost of laser systems, laser material processing has gained increased importance in a variety of industries. Navy, aerospace, automotive, defence and many other sectors are widely adapting laser technology for welding, cutting and hardening [1].

Laser cladding can be used to good effect in processes which require a high productivity combined with flexibility without compromising quality.

A high and uniform quality with a low heat input makes this process suitable for a wide range of applications in which minimum distortion is desired. Examples of industrial laser cladding applications are [2]: improved wear resistance of bearings, valves, axles, cutting tools and other parts where the working conditions are very severe; improved corrosion resistance; repairing turbine parts, moulds, tools; building up complex geometries.

Laser cladding can be used to improve resistance to wear and corrosion of components in the metallurgical industry.

Laser cladding was defined as a process used to melt a material having different metallurgical properties on a substrate by means of laser beam [3].

Thus it was found that by altering the power density, duration of laser action, feed speed, powder feed speed, granulation and powder density, the complex of physico – mechanical properties within the superficial layers of preset size. Also a good quality of the layers deposited implies lack of cracks, of porosity, good bond with the substrate and a low dilution of the material covering the substrate and minimum roughness [3].

Copper alloys with 9-11% Al features, in addition to high corrosion resistance, good casting and hot forming properties and heat treatment hardening capacity of martensitic quenching and tempering.

Classical quenching consists of [4], heating at temperatures of 980-1000 °C followed by rapid cooling in water. Subsequent tempering to 400-550 °C, has hardening effect. Thus the $CuAl_{10}Fe_4Ni_4$ alloy after quenching from 980 °C in water and tempering to 400 °C, increases its hardness from 170-200 HB to over 400 HB.

In the special Cu-Al alloys there are additions of Fe, Ni, Mn, which change the solubility of aluminum in copper and lead to new phases. Iron polishes granulation and improves mechanical and antifriction properties. In Fe-rich alloys it may occur an intermetallic compound $FeAl_3$ with hardening and embrittlement effect. Nickel and manganese increase corrosion resistance and provide further hardening by solid solution alloying [5-7].

Multilayer deposition of aluminum bronze powders injected onto the laser melted surface has the advantage of making thick layers with uniform chemical composition and properties throughout the section.

The paper presents the wear behaviour on rotating disk with abrasive paper of laser cladding layers with aluminum bronze powders compared to steel samples and aluminum bronze classically quenched.

## 2. Experimental conditions

For deposition, use was made of powder of bronze with alluminum „Rototec Proces FRIXTEC

CASTOLIN U.S.A.”, having the following chemical composition: 9.5% Al; 2.2% Fe; rest Cu.

Since the coating with aluminum bronze on the steel support indicated a low quality of the deposited layers geometry (rough surface, thin deposit and micro-cracks), its deposition on a buffer layer of nickel alloy has been experienced and a very good deposition on steel substrate was found.

The Nickel based alloy used in the laser cladding is Ni-Cr-B-Fe-Al with the following chemical composition: 8.9% Cr, 4.5% Fe, 5.1% B 2.4% Al, 0.6% Cu, rest Ni.

The basic material used in the experimental research is steel 1C45, SR EN 10083-1:1994.

Laboratory experiments were conducted on a $CO_2$ continuous wave system, type 1400 W Laser GT (Romania), with working mass in x-y-z coordinates and computer programming of the working regime, provided with a powder injection system on the melted surface by means of laser, existing in SC UZINSIDERENGINEERING Galaţi.

Laboratory tests used a 1.8 mm diameter laser beam, which made partially overlapping parallel strips. Final thickness of the layer was achieved by superposition of five layers. To determine the optimum deposition regime the added material flow rate was varied, Q, from 53 to 150 mg/s, beam power, P, from 900 to 1200 W, surface scanning speed, v, from 5-7 mm/s and transverse movement step, p, 1 to 2 mm. The nickel alloy buffer layer was deposited by the superposition of two layers, under the following conditions: Q = 53 mg/s, P = 1100 W, v = 7 mm/s, p = 1 - 2 mm. Table 2 shows the experimented working regimes and thickness, h, of the deposits obtained. Deposition regime was characterized by energy density factor $K = P / d * v$, which ranged within 79.3 ÷ 100 J/mm$^2$.

The characterization of particles shapes was made on the optic microscope, analyzing the free particles of the powders distributed into a single particles layer, between two glass plates. For the purpose of metallographic analysis, the powder was embedded by cyano-acrylate adhesive and prepared by grinding, polishing and chemical attack with Nital 2% or ferric chloride and examined at optical microscope Olympus BX51M Japan, with digital acquisition of image. To determine the micro hardness of the powder particles micro hardness, apparatus PMT-3 with penetration loading by 100 g was used. Vickers microhardness was calculated according to the SR EN ISO 6507-1:2002 standard. Results are presented as a mean of three measurements.

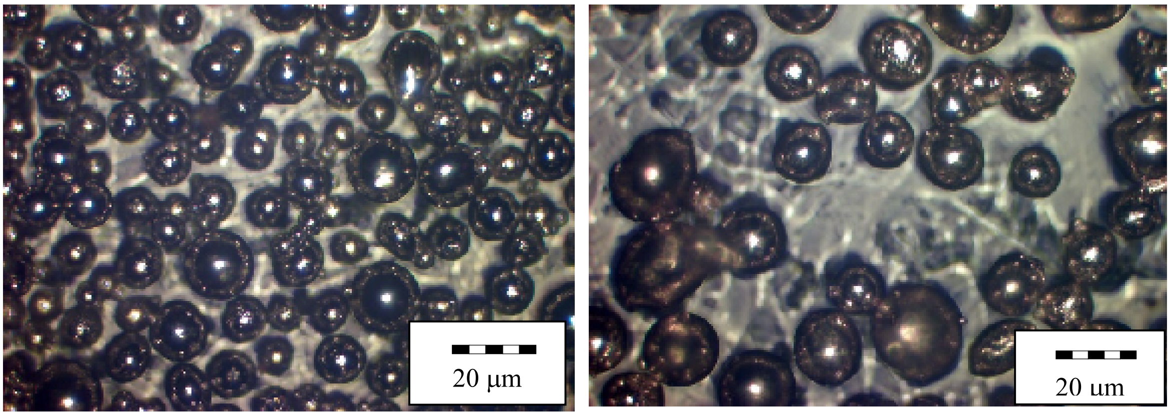
Microstructural analysis was performed on samples cross-section, perpendicular to the direction of laser processing. The microstructure of the samples was observed by optical microscopy Olympus BX 51 M.

The abrasive wear behavior of laser deposited layers with aluminum bronze powder has been studied according to STAS 9639-81. The method uses a connection of peg/disk friction of class IV-1. The method consists in pressing sequentially, under identical conditions, two samples of dimensions 6.2 x 6.2 mm, one of the material examined deposited by laser and the other from a material chosen for comparison purpose – improved aluminum bronze classically quenched on a rotating disk covered with grinding paper of 120 grains. A mechanism for radial displacement of the tube with 0.5 mm/r provides a spiral movement on the surface of the rotating disk.

A device for implementing a load of 8.387 N ensured perpendicular pressing of the sample on the grinding paper at the pressure of 0.215 N/mm$^2$. At disk speed of 25 rpm, a number of 131 rotations have provided a length path of 82 m.

## 3. Results and discussions

Fig. 1. shows the aspect of the powders used. The powders have a spherical shape caused by atomization of gas.




*a.* *b.*

***Fig. 1.*** *Aspect of nickel base powder – a, and copper base powder - b*

In the case of nickel base powder, the **microscopic analysis** on samples embedded, polished and attacked with Nital 2% highlights the relative compactness. Particle microstructure consists of numerous intermetallic compounds (NiB, $Ni_2B$, CrB, $Cr_3B_4$ and FeB) distributed in a very fine martensitic matrix [3].

**Microhardness** determined on the polished section of the particles under 100g load was HV0.1 = 9522.2 MPa.

In the case of copper base powder, the microscopic analysis on samples embedded, polished and attacked with ferric chloride reagent highlights the microstructure of particle.

Their structure consist of intermetallic compound Fe - Al distributed in a very fine matrix [4].

**Microhardness** determined on the polished section of the particles under 100g load was HV0.1 = 2766.5 MPa.

Macroscopic analysis of the laser deposition of aluminum bronze highlights the deposited layer surface quality, thickness and adhesion to the support.

Thick layers with plain surface of cladded layer (Figure 2) may be remarked.

The layer thickness was h = 0.38 – 1.23 mm.

The surface layer is rough (Figure 2) and requires subsequent removal by machining of a relatively large layer.

Macrostructures of the laser deposition of aluminum bronze show a low adhesion to carbon steel support, which can be explained by the poor metal link due to the low solubility of solid copper in iron.

***Fig. 2.*** *Surface of samples cladded by thick layers of aluminum bronze*

The layer thickness strongly depends on the sweeping speed and additional material injection volume. The maximum thickness was found where the sweeping speed was minimum and additional material injection volume was maximum. As laser beam mainly gives the energy required to melt the additional material, the sweeping speed has to be correlated to the additional material flow. The higher the additional material flow, the smaller the sweeping speed which ensures maximum deposited layer thickness.

The decrease in the added material flow rate to 53 mg/s and the use of a buffer layer of nickel alloy, unlimitedly soluble as solid in both iron and copper, increased the adhesion to the steel support and to the deposited layer. The layer quality was significantly improved as this becomes uniform, compact, without solidification shrinkage cracks and with practical applicability. Note that when using a 1.8 mm diameter laser beam on the surface being processed, the max. layer thickness is obtained on a step of the transverse movement of the 1.5 mm sample.

Figure 3 shows the microstructure of the deposited layer for sample with Ni alloy middle layer (Q = 53 mg/s, P = 1100 W, v = 7 mm/s, p = 1 mm, K = 87.30 J/mm$^2$, h = 0.64 mm). Good support adherence of the deposited layer is visible. At the fusion limit there are no compactness defects or inclusions of metal.

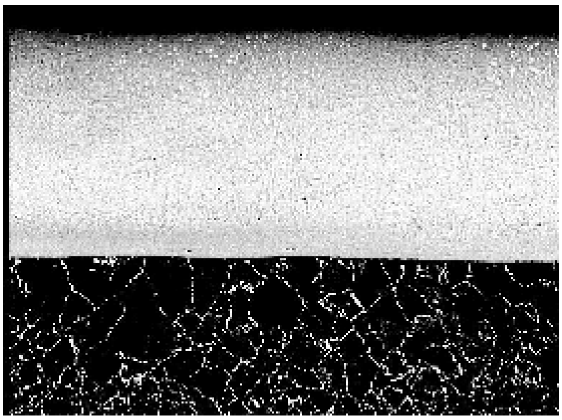


***Fig. 3.*** *Microstructure of the deposited layer with Ni alloy middle layer, general view, x500*

The microstructure of the deposited layer results from melting and ultra-fast solidification of the added material, followed by a partial self-tempering in the overlapping area of the strip deposited i.e sub-layer tempering when an additional layer is deposited.

The microstructure is fine, columnar dendritic, locally with needle type appearance specific to hardening martensitic structures with interdendritic separation of an intermetallic compound Fe - Al.

The microhardness of the laser cladding layer was HV0.1 = 3500 – 8000 MPa. Microhardness maximum corresponds to a working regime – Q = 86 mg/s, P = 1000 W, v = 7 mm/s, p = 2 mm, K = 79.36 J/mm$^2$, h = 0.38 mm, due to the presence of compound $FeAl_3$ in large amount and stability of the martensitic structure to the quick tempering process.

The regime considered optimum – Q = 53 mg/s, P = 1100 W, v = 7 mm/s, p = 1.5 mm, K = 87.30 J/mm$^2$, h = 0.74 mm, was used to study the behaviour to the abrasive wear of the laser cladding. Table 1 presents results from wear tests (mass wear, mass wear/length of path covered) in rotating disk with abrasive paper for both laser cladding samples and those classically hardened in volume and the support. The results are the average of three determinations.

It may be noted that the laser cladding alloy is more resistant to abrasive wear than samples classically hardened, and than the support. This is due to higher hardness obtained after laser cladding.

In Fig. 4 – 6, 3D images are presented made with an Image J software, of the sample areas obtained from the abrasive wear test.

***Table 1.*** *Abrasive wear behaviour of the support, the deposit aluminum bronze powder, and the classically hardened aluminum bronze*

| **Material** | **Initial mass [g]** | **Final mass [g]** | **Mass wear [g]** | **Length run [m]** | **Wear/length run U/L [g/m]** |
|---|---|---|---|---|---|
| 1C45 | 2.9150 | 2.7270 | 0.188 | 82 | 0.00229 |
| Laser cladding aluminum bronze | 3.1638 | 3.0818 | 0.082 | 82 | 0.001 |
| Aluminum bronze classical quenching | 2.6625 | 2.5379 | 0.1246 | 82 | 0.00152 |

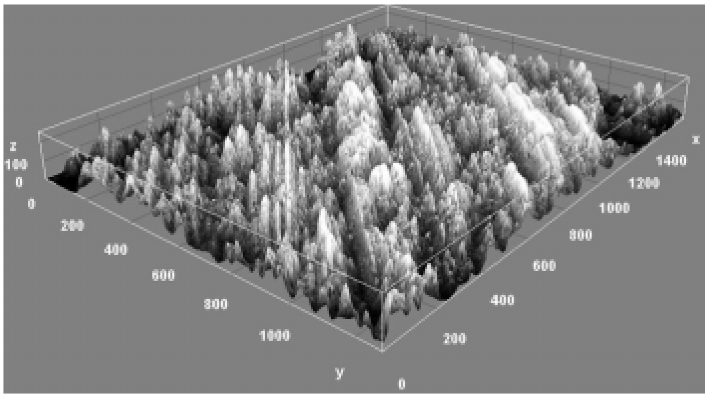



***Fig. 4.*** *3D image of the 1C45 surface subjected to abrasive wear*

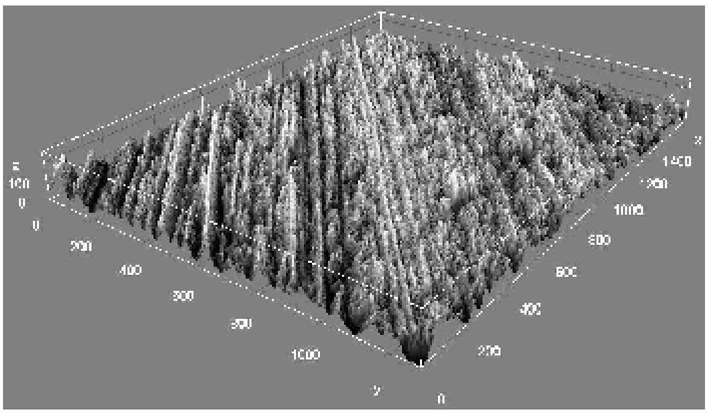


***Fig. 5.*** *3D image of the laser cladding surface subjected to abrasive wear*

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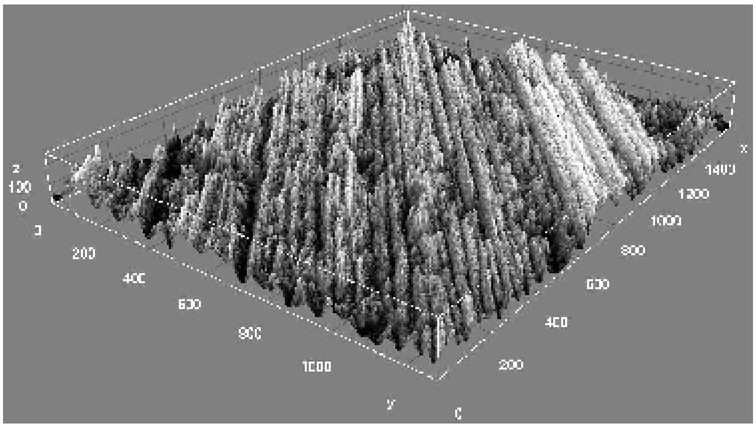


***Fig. 6.*** *3D image of the classically hardened aluminium bronze surface subjected to abrasive wear*

## 4. Conclusions

When using multi layers coating by continuous wave laser beam, thick layers of copper alloy from the Cu-Al-Fe system may be achieved featuring higher wear resistance, and good density and adherence to the under layer through a thin dilution layer.

Laser coating by powder injected into a melt bath is a complex process of mass and heat transfer, which is efficient when associated with a powder injection system in continuous steady flow. With the coating process by laser beam of given power and dimensions, hardness and thickness of the deposited layer depend on the additional material flow, surface sweeping speed, initial sample temperature, number of superimposed layers and the extent of laser strips superimposition.

The optimum deposition regime was nickel alloy middle layer, regime – Q = 53 mg/s, P = 1100 W, v = 7 mm/s, p = 1.5 mm, K = 87.30 J/mm$^2$, which ensured a 0.74 mm thick layer with a microhardness HV0.1 = 3895 MPa. The microstructure of the deposited layer is fine, columnar dendritic, with interdendritic separation of an intermetallic compound Fe - Al.

Abrasive wear behaviour of laser cladding layers of aluminum bronze showed a higher resistance compared to steel 1C45, and aluminum bronze classically quenched.

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