

# Selected properties of laser cladding coatings shaped using Flow drill technology

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**Abstract.** The paper presents the investigations of selected chemical and mechanical properties as well as macro- and microstructure of materials formed using thermal drilling process (Flow drill). The aim of this study was to determine the microstructure of the coatings produced using laser cladding with powder technology. The coatings were produced on the low-carbon steel using 1 kW disc laser. After modification of surface, the thermal drilling process was applied. To produce all coatings, the pure copper powder was used. In this study the laser power equal of 500, 700 and 900 W were used. The microstructure, chemical composition (EDS) and microhardness were investigation. It was found that the surface modification of low carbon steel and next conducted thermal drilling process caused change the surface properties on the hole flange. It was found that surface modification of steel using laser cladding with cooper powder and next Flow drill process contributes to the change in microhardness and chemical composition on hole flange.

## 1 Introduction

Surface engineering technologies have influenced on the development of other production technologies and materials processing such as surface modification [1 - 13] as well as metal forming processing [14-22]. One of the metal forming processes is the hole flanging which is intended to increase the diameter of the previously cut hole and to form around it the conical or cylindrical flange. The traditional method is commonly known and consists of flanging through the cylindrical punch with a tapered end which is intended to pierce through the material pointwise and then to form a corresponding hole shape and a flange around it. Technological advances have strongly influenced the conventional edge drilling technology by Flow drill technology. Many characteristics of this process have benefited from it compared to the older known processing methods. There are several important advantages of this process [14, 15]. Firstly, in the thermal drilling process there is no material loss. Material is plasticized and then formed. Thanks to this, material is fully utilized to fabricate the collar and forming the sleeve. Additionally the Flowdrill technology allows the produces sleeve up to three times the height of the output material. Material

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thickness may range from 0.5 to 10 mm. A slight increase in the recommended values of the machining parameters allows the edge thickness to increase by several percent. The thermal drilling is a one-step process, it does not require any change of tools or additional treatment before and after the process, and the time needed to produce the hole flange is small, just a few seconds. In addition, this process is very fast and easy to automate, making it suitable for serial or mass production.

This work is focused on the issue of the hole flanging using the thermal drilling technology (Flow drill). The process was used on materials with coating produced by the laser cladding process which is commonly used [1-4, 11]. Selected properties such as macro- and microstructure, coating thickness, microhardness, and chemical composition were investigated. The results were analysed and they are very promising.

## 2 Research Methodology

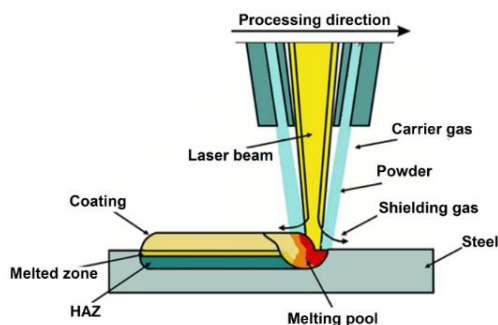
### 2.1 Materials and technology

The output material used for the laser cladding and thermal drilling processes was the general purpose structural S235JRH steel. Its chemical composition of this material was shown in Table 1.

**Table 1.** Chemical composition of S235JRH steel used for testing.

Steel grade	Maximum weight share [%]				
	C	Mn	P	S	N
S235	0.7	1.40	0.045	0.045	0.009

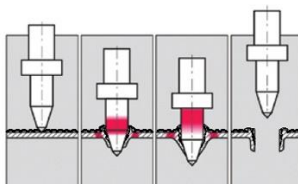
Specimens of 30 x 24 x 20 mm with a wall thickness of 2 mm were cut from the profile. On the specimens were produced copper coatings using laser cladding technology. On the series of specimens of S235JRH steel the copper coatings using laser beam have been made. The manufacturing process was carried out at the Industrial Institute of Agricultural Machines in Poznan. The TRUMPF laser model TruLaser Cell 3008 was used for produced specimens for research. The working area of this device includes the axes: X - 800 mm, Y - 500 mm and Z - 400 mm. The laser device includes components such as a working chamber, TruDisk 1000W disk laser equipped with a three-stream powder feeding system as well as cooling and filtering circuits. Prior to making the coatings, the specimens must be properly prepared: the surface of each was polished and cleaned. The laser cladding process was carried out in a closed chamber where powdered material was supplied coaxial to the laser beam by carrier gas as shown in Figure 1.



**Fig. 1.** Scheme of a laser cladding process with additive material in the form of powder.

The laser head contains three powder delivery nozzles and a central channel through which the shield gas and the laser beam are supplied. The coatings were prepared for each specimens using varying laser power parameter (700, 800 and 900 W). The process was carried out with constant parameters: feedrate 600 mm/min; laser beam diameter 2 mm; flow rate of gas supplying the powder (helium) 8 l/min; shield gas flow rate (argon) 8 l/min; powder feeder rate 0.8 obr/min.

Specimens with laser clad coating were subjected to a flow drill process. Holes and flanging for each specimens were made on a JET JMD-18VS drilling machine. The machine was equipped with a handle with cooling ring in which a drill bit of 7.3 mm was mounted. The tool was secured with a Flowdrill FDKS paste that was applied each time before the hole was made to protect the tool from high temperatures. Tools turnover amounted to 3000 rev/min, and feed rate was performed manually. Figure 2 shows a scheme of the hole flanging process in materials with coating produced using laser cladding with powder technology.



**Fig. 2.** Scheme of flanging using Flowdrill technology in materials with laser clad coating.

## 2.2 Microstructure and microhardness study

Macroscopic observation of all specimens was performed using the magnifying glass. Color as well as presence or absence of cracks and porosity were determined. Photos were taken using the Nikon D5000. Microstructural observations were made using Huvitz HRM-300 optical microscope with digital image recording. For the tests, metallographic cross section were made. The specimens were cutting and next placing in conductive thermoset resin. To reveal the microstructure of specimens substrate and its surface, the mixture of nitric acid and ethanol was used. Microhardness tests were performed using the Vickers method on the Buehler microhardness tester.

## 2.3 Chemical composition study

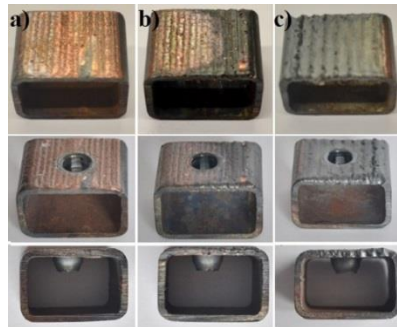
The chemical composition of specimens was examined using the scanning electron microscope (SEM) Vega Tescan equipped with PGS's Prism 2000 EDS (Energy Dispersive Spectroscopy) system. EDS analyzers allow both surface and volumetric identification of the chemical elements contained in the test material. A linear analysis of the chemical composition was carried out for each specimen.

# 3 Results of study

## 3.1 Microstructure and microhardness results

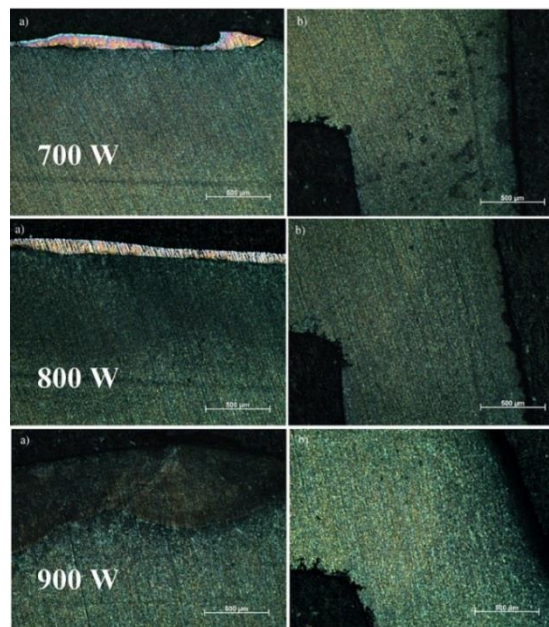
In Figure 3 were shown a macroscopic images of three samples with coatings produced using different laser beam powers. For the first specimen (700 W), it can be seen that the resulting coating has a copper color without discoloration and other changes. Width of tracks are the same. No deformation and no cracks were observed. For the specimen

produced using laser beam power equal 800 W, the part of surface have color of copper, but slightly darker than on first specimen. It was also found the dark area that results from excessive heating of the workpiece during the laser cladding process. In addition, no cracks, porosities or other surface damage were noted. In the case of specimen produced using laser beam power equal 900 W, the surface is mostly gray with one track of copper-colored track. Deformation of track was much greater than that previous specimens. Based on macroscopic examination of three series kind of specimens produced using different laser beam power, it was found that the hole flanging process was successful and the form of holes and flange of all specimens were very similar. No geometric defects were observed in the form of cracks or other discontinuities of the material.



**Fig. 3.** Specimens with coating produced using laser cladding at laser beam power and after Flowdrill a) 700 W b) 800 W and c) 900 W.

On the basis of the conducted examinations of metallographic cross section of specimens the microstructure was determined. The results of microstructure were shown in Figure 4. In the case of specimens produced using laser beam power of 700 W, there are three distinct zones in the material: a distinctly uneven copper layer, a transition layer, and the substrate.



**Fig. 4.** Microstructure of a specimen with a laser cladde coating of cooper : a) coating, b) hole flange.

On the hole flange edge, it was found that the distinctive copper coating disappears, leaving only the transition zone. In the case of specimens produced using laser beam power of 800 W, there also three separate zones. This time the copper coating is spread evenly over the whole length, and it disappears on the edge of hole flange. The microstructure of specimen produced using laser beam power of 900 W, clearly differs from the previous. Higher temperature of laser claddind process caused the copper powder was mixed with the substrate material to a much greater extent than in the case of two previous kind of specimens. This results in a thicker outer coating without copper-colored and a difficult-to-find border of the transition zone. It is also possible to observe the absence of pores within the rim of the rolled edge. Microstructural studies additionally included a microhardness test of hole flange. For each specimens, five measurements were made in the cross section of the flange from the inner wall to the inside of the material. The results microhardness measurments for all specimens are present in table 2.

**Table 2.** Microhardness of specimens.

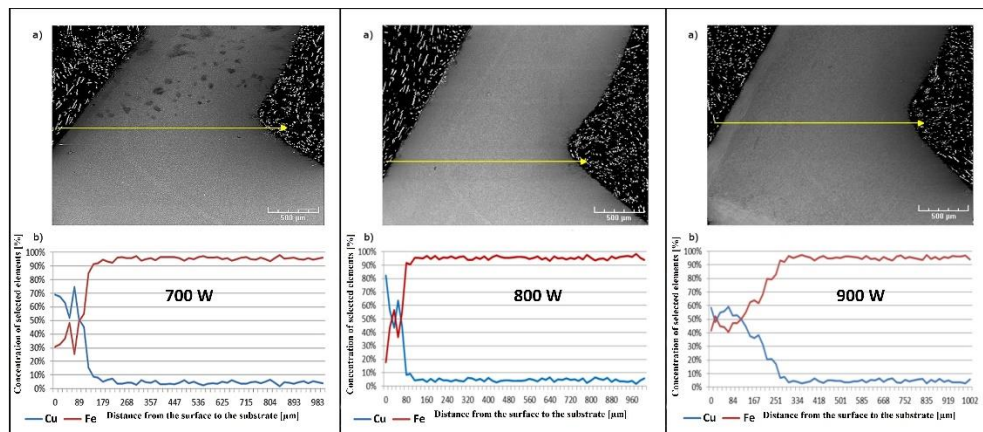
Measurement number	Microhardness [HV]		
	700W	800W	900W
1	255	236	221
2	220	199	176
3	196	161	213
4	274	213	171
5	220	193	171
Average:	233	200.4	190.4

The highest micro hardness value was achieved with the specimen produced using laser beam power equal to 700 W. This hardness was about 22% larger than the specimen produced at 900 W and about 16% larger than the specimens produced using 800 W. With the increase in laser beam power, the substrate was melted and mixed with the coating material, which is harder than substrate. Hence, at the smallest power of the laser beam, the surface of the flange is characterized by the highest microhardness. Increasing the power of the laser beam causes mixing the coating material with the soft substrate.

### 3.2 Chemical composition study

A linear analysis of the chemical composition of the specimens was made. Content of copper and iron was determined (Fig. 5). From the diagram (700 W), it can be determined that the produced coating have about 100 μm thickness in the material. The copper content on the surface varies considerably from about 75% to 40%, and beyond this 100 μm, a sharp decrease in the percentage of copper and a stabilization of about 5% was observed. In contrast to copper, the concentration of iron was change. For specimen produced using 800 W, the situation is similar to that of the specimen produced using 700 W. The coating containing copper concentration of about 50% reached 70 μm deep into the test material. The initial high content of 80% quickly declined, stabilizing between 45% and 65%. This time the iron content was interwoven with the copper in the top layer, where the rise and fall were recorded, but the value itself did not exceed 55%. As the graph shows, after a distance of 70 μm, the content of the elements has been stabilized after a visible drop of copper concentration to about 5% and a sharp increase in iron concentration to about 95%. In the case of specimen produced using 900 W, a large difference in the course of the concentration change can be observed compared to the other two kind of specimens. The copper content in the top of coating did not exceed 60% and to about 120 μm did not decrease below 50%. Iron content in the top of coating was the highest of all three

specimens, its concentration ranged between 40 and 50%. Closer to the steel substrate there is a gradual decrease in copper content and an increase in iron content which, as in previous cases, has stabilized, reaching values of about 5% for copper and about 95% for iron approximately 260  $\mu\text{m}$  from surface.



**Fig. 5.** Chemical composition of specimen with copper coating produced using laser cladding: a) direction of linear composition analysis b) concentration of Fe and Cu.

## 4 Conclusions

Both technology presented in this work, laser cladding as well as Flowdrill are innovative technologies. Combining these two processes allows get high-quality connections in a very short time. Additionally both of these methods are very quick and easy to automate. Laser cladding and Flowdrill processes are characterized by the fact that they are based on the treatment of elements with very high temperatures.

Based on this studies can be drawn the following conclusions. From the macrostructure study, it appears that the copper layer made with laser technology did not negatively affect the quality of the hole flange. For all three kind of specimens no discoloration, cracks or porosities were observed and the inner surface of the flange was good quality. Analysis of the chemical composition showed an increased copper concentration at the inner wall of flange. The process of thermal drilling caused the diffusion of coating material to the steel substrate. The method described may be used in the case of joining materials which have previously been subjected to surface treatment.

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