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Thermal analysis of nozzle for powder feeding in High Power Diode Laser (HPDL) powder surfacing

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ABSTRACT

Purpose: Purpose of these researches was to determine the influence of High Power Diode Laser (HPDL) powder surfacing parameters, material type and shape of the nozzle for powder feeding on the temperature field of the nozzle.
Design/methodology/approach: Different materials for manufacturing of the nozzle for powder feeding during HPDL powder surfacing and different shapes of the nozzle were tested to establish the optimum shape and select the material that ensure lowest heating of the nozzle. Reflection coefficient of the infrared laser radiation of 808 nm for the tested materials were determined as a function of a temperature. Temperature of the nozzle tip was measured and determined as a function of surfacing parameters. Life time of the different nozzles was determined.
Findings: It was shown that the nozzle made of copper body and thin-walled tube made of austenitic stainless steel ensures much higher life time of the nozzle and also higher process efficiency compared with nozzle made of copper.
Research limitations/implications: It was found that decreasing the distance from the nozzle tip of thin-walled tube made of austenitic stainless steel to the weld pool surface resulted in increasing of the process efficiency but too short distance is the reason of extensive heating of the nozzle.
Originality/value: The optimized shape of the powder feeding nozzle made of thin-walled tube made of austenitic stainless steel guarantee unlimited lifetime of the nozzle and high surfacing efficiency over 95%.
Keywords: Welding; Surfacing; High Power Diode Laser

1. Introduction

Laser powder surfacing, as one of areas of laser application, is currently being developed in many branches of industry. Possibility of precise control of fusion depth makes that the dilution of the surfacing material by substrate material is insignificant (from 3 to 10%), especially in the laser surfacing with powder addition [1, 2, 3]. The chemical composition of laser deposits is not significant different from chemical composition of the additional material even in the first layer. Therefore it is possible to obtain required utility properties in the first layer of deposit, and the material excess for finishing does not exceed 0,2-0,3 mm. The high power density of laser beam (reaches even 10^7 W/cm^2 at atmospherical conditions) ensures minimum heat effect on the workpiece. Thus, thermal stresses and deformations of the workpiece are very low or even neglectable [1-5].

The development of direct-diode laser systems has enabled recently the arrival of the new generation of high power diode lasers which are of interest for material processing because of their beneficial features, compared with molecular CO_2 and solid state Nd:YAG lasers. Thanks to rectangular shape of HPDLs laser beam, with a top hat profile in one direction and Gaussian like in the other, the HPDL beam is ideal for surface treatment applications. Additionally, in comparison to CO_2 lasers, HPDLs emit at short wavelengths in a range 808-960 nm thus the absorption of HPDL beam is significantly higher. Some authors indicate that the absorption of HPDL beam for metallic materials is even several times higher than absorption of CO_2 laser beam [1, 2, 5].

There are two main techniques of laser powder surfacing, depending on the method of powder applying. The powder can be injected directly into the weld pool and melted inside the weld pool and then the deposit layer is formed. The powder can be also preplaced on the substrate surface and then remelted by the laser beam. The powder injection technique provides significantly more accurate control of fusion depth and higher efficiency compared to the powder preplacing technique. Usually the powder is injected into the weld pool via nozzle set at an angle to the substrate material [1-10, 12, 15]. The distance from the weld pool surface to the outlet of nozzle for powder feeding must be short to ensure high efficiency of laser cladding with powder injection technique. Thus the nozzle for powder feeding is intensive heated and the tip of the nozzle can be easily overheated and melted. That is why the construction of the nozzle for powder feeding must be designed for extreme working conditions [1, 10-15].

The aim of this work was elaborating and designing a construction of nozzle for powder feeding which is resistant to heating during laser cladding, when short distance from weld pool surface to the nozzle outlet is applied, which is indispensable to achieve high efficiency of laser cladding process with powder injection technique.

2. Experimental

The laser used in the cladding process was high power diode laser with maximum output power 2,3 kW, Fig. 1, Table 1. The rectangular HPDL beam spot of size 1,8×6,8 mm, at focal length 82 mm, was focused on the metallic clean surface of carbon steel plates S355NL - EN 10 113, 8 mm thick. The substrate was moved under the stationary beam by a numeric XY-table. The cladding process was carried out along both short and long side of the rectangular HPDL beam spot. The nickel base powder was supplied, by a rotary powder feeder and Ar carrier gas, via a cylindrical nozzle and also a nozzle with flat outlet. The powder feeding system enables precise control of powder feeding rate in a rage from 0,8-25 g/min. Laser cladding experiments were carried out using two type of nozzles for powder feeding. One nozzle for powder feeding was made of copper and the second one was made of two type of materials. The nozzle body was made of copper and connected with a thin-walled tube (nozzle tip) made of austenitic stainless steel. Nozzles for powder feeding made of copper are commonly used in industrial systems for laser powder cladding with CO_2 and Nd:YAG lasers. The construction of the nozzle for powder feeding with a thin-walled tube made of austenitic stainless steel was designed, manufactured and patented in Welding Department of Silesian University of Technology. To determine the temperature of the nozzle tip during laser surfacing, stringer beads of deposit were produced at different laser output power, surfacing speed, powder feeding rate, different distance of nozzle tip from weld pool surface and nozzle inclination angle. The commercial grade argon was used as a shielding gas supplied generally at 6 l/min via cylindrical nozzle. The temperature of the nozzle tip for powder feeding was measured using a temperature recorder with Ni-NiCr thermocouple. The temperature of the nozzle tip was measured for 60 seconds from start of the laser cladding process to ensure stable thermal conditions of the nozzle tip. The absorptions of High Power Diode Laser beam for materials used for manufacturing the nozzles (copper and stainless steel) were measured by a spherical method.

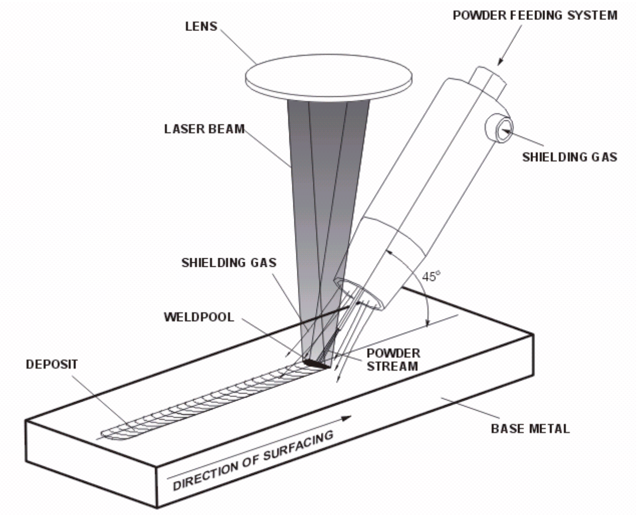

Fig. 1. A scheme of laser powder surfacing process carried out along the short side of the rectangular diode laser beam spot with powder injection in front of the weld pool

3. Results and discussion

It was found that, the temperature of the tip of the nozzle for powder feeding was stabilized after 6 seconds from the start of laser cladding process. The temperature of the tip of the nozzle for powder feeding does not depend directly on heat input of laser surfacing, but separately on the laser out put power and the surfacing speed. The decrease of the surfacing speed does not cause significant increase of the temperature of the tip of the nozzle for powder feeding. Significant increase of the temperature of the tip of the nozzle for powder feeding was observed when the laser output power was increased, especially during laser surfacing process along the short side of the rectangular diode laser spot. It was found that heating of the nozzle for powder feeding is caused mainly by the laser radiation reflected from the surface of the weld pool. A numerical analysis of laser powder surfacing process showed that the absorption coefficient of HPD laser beam at the weld pool surface is approximately 0,65. Thus, 35 % of the output power of the HPD laser beam is reflected from the weld pool surface. Direction of reflected laser beam radiation depends strongly on the shape of HPD laser beam and shape of the weld pool.

Table 1.
Technical data of the HPDL ROFIN DL 020

Wavelength of the laser radiation	808 nm ±5 nm
Maximum output power of the laser beam (continuous-wave)	2300 W
Laser power range	100 ÷ 2300 W
Focal length	82 mm / 32 mm
Laser spot size	1,8 × 6,8 mm / 1,8 × 3,8 mm
Range of the laser intensity	0,8÷36,5 kW/cm^2

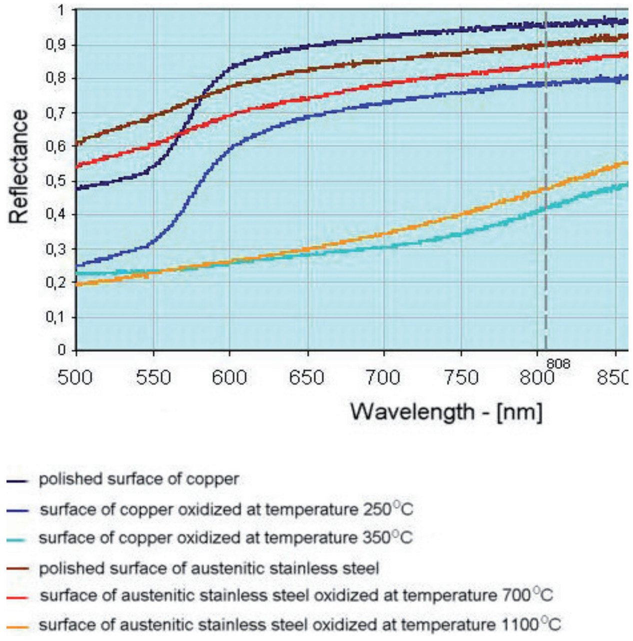

Fig. 2. Influence of the material type and surface condition of the nozzle for powder feeding, on the reflection of laser radiation

The study of the construction of the nozzle for powder feeding has shown that the nozzle made of copper was heated more intensive, in spite of very high thermal conductivity, than the nozzle made of copper body and thin-walled tube made of austenitic stainless steel. This phenomenon is a result of reflectivity of the laser energy from the surface of copper. The polished surface of copper reflects 95 % of the output power of the HPD laser beam, at ambient temperature. However increase of temperature of the copper surface causes intensive oxidation of the surface and the absorption coefficient of HPD laser radiation is increased, Fig. 2. Heating of the copper nozzle for powder feeding at temperature of 350 ºC, in the air atmosphere, causes formation of CuO on the surface of the nozzle tip. Layer of Cu oxides on the copper nozzle decreases the reflection of the HPD laser radiation by approximately 50 %. The nozzle for powder feeding made of polished austenitic stainless steel is high oxidation resistant so the absorption of laser radiation is significantly lower, approximately 15%, in wide range of temperature, Fig. 3. Moreover, the area of absorption of the laser radiation is significantly limited when the thin-walled tube of 0,2 mm thick wall is applied. The copper body of the nozzle is not subjected to laser radiation reflected from the weld pool and also the copper body ensures intensive heat abstraction from the austenitic stainless steel thin-walled tube. The polished surface of austenitic stainless tube ensures high oxidation resistance up to the temperature of 1100 ºC. Over the critical temperature the tube surface is oxidized and the absorption of laser radiation is also radically increased. The increase of width (S) of the austenitic stainless steel thin-walled nozzle does not cause significant increase of its temperature. The reason of this phenomenon is that the increase of the external area of nozzle, when the laser radiation is absorbed, causes increase of the internal area of the nozzle, that is cooled intensively by powder particles and the carrier gas, Fig. 4. The minimum distance from the weld pool surface to the outlet of nozzle for powder feeding, during laser surfacing process carried out along the short side of the rectangular diode laser beam spot with powder feeding in front of the weld pool, ensuring high life time of the nozzle and also high process efficiency is limited to 14.0 mm. Moreover the reflection of the HPD laser radiation from the weld pool surface limits the nozzle inclination angle β to 45˚, Fig. 5.

Relative low divergence of the HPD laser beam in the plane parallel to the long side of the rectangular diode laser spot ensures a minimum heating of nozzle for powder feeding during the laser surfacing process carried out along the long side of the rectangular diode laser beam spot with powder feeding in front of the weld pool, Fig. 6. Thus in this case the minimum distance from the weld pool surface to the outlet of the nozzle for powder feeding, ensuring high life time of the nozzle and also high process efficiency, is limited to just 5,0 mm.

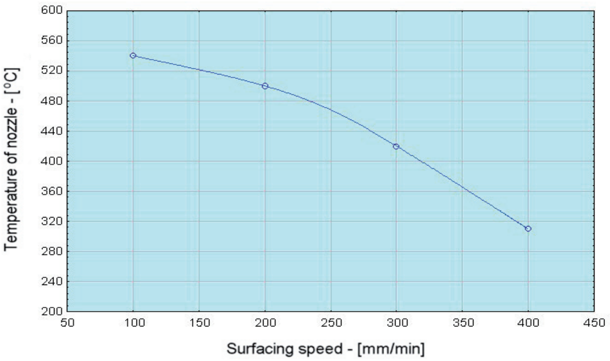

Fig. 3. The influence of the surfacing speed of laser powder surfacing process on the temperature of nozzle at 1000 W of laser power

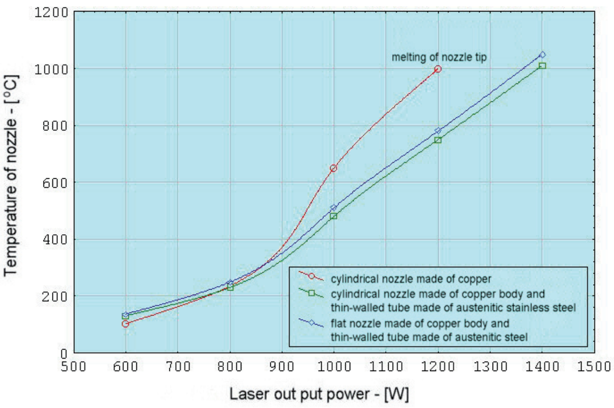

Fig. 4. The influence of the construction of the nozzle for powder feeding and laser out put power of laser powder surfacing on the temperature of nozzle at surfacing speed 200 mm/min

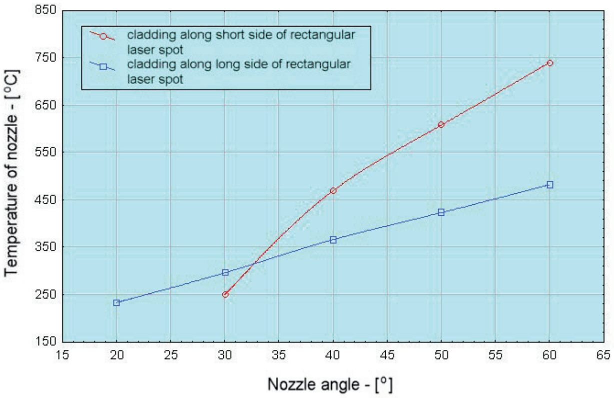

Fig. 5. The influence of the nozzle inclination angle and the direction of laser powder surfacing on the temperature of the nozzle for powder feeding. Surfacing parameters: laser output power 1000 W, surfacing speed 200 mm/min

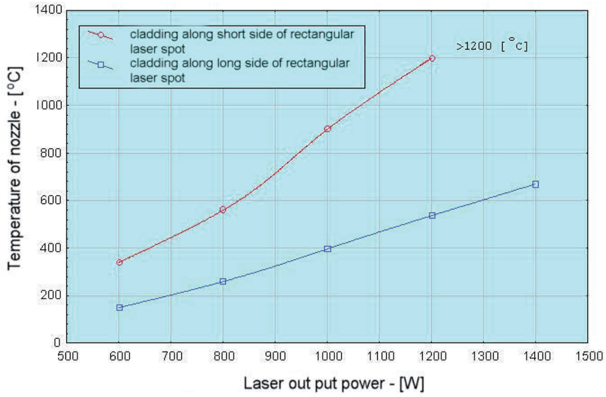

Fig. 6. The influence of laser output power and the direction of laser powder surfacing on the temperature of nozzle at surfacing speed 200 mm/min

4. Summary

Intensive heating of the outlet of the nozzle tip for powder feeding during the laser powder cladding is mainly caused by the laser radiation reflected from the surface of the weld pool. Long life time of the nozzle for powder feeding and stability of the powder stream during the HPD laser powder surfacing are ensured by nozzle made of materials that are characterized by low absorption of laser radiation in wide range of temperature, e.g. austenitic steel.

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