УДК 621.791.92

Design of Multi-Channel Nozzles for Laser Cladding

Zhuk[1] R.O., Anyakin[1] M.I., Qunli Zhang[2], Zhijun Chen[2]
1-National Technical University of Ukraine "Ihor Sikorsky KPI", Kyiv, Ukraine
2-Institute of Laser Advanced Manufacturing, Zhejiang University of Technology, Hangzhou, 310014, China

Annotation: *Gas-powder laser cladding technology is widely used nowadays either to restore surface of tools and parts or to modify part's properties (wear resistance, corrosion resistance etc).*
Application of multichannel nozzles for the delivery of gas-powder streams into laser processing zone boosts the range of technological applications. This research is focused on simultaneous introduction of different powder into the processing zone. Another scope of interest is the control of powder distribution on the surface of workpiece and manipulation of powder concentration distribution on the go. Two different laser types were used – fiber and High-Power Diode lasers.
Research activities included numerical simulation of gas-powder stream propagation inside the nozzle and into the ambient atmosphere, printing of prototypes with STL technology and their experimental validation. The performance of prototypes was evaluated and the most promising ones were selected for manufacturing.
Original nozzles for the delivery of gas-powder mixtures with controllable distribution of powder concentration were designed and manufactured. Single clads were made using these nozzles and clad characteristics were compared. It was found that the outcome of laser cladding process significantly depends on the distribution of powder concentration, geometrical characteristics of nozzle inner cavity, powder and carrier gas flowrate. Manufacturing of parts with complex shapes is one of the most promising applications for the designed nozzles.
Keywords: laser cladding; powder delivery nozzle

In-depth review of papers on coaxial laser gas-powder cladding is given by Pinkerton [1]. Author states that modern computational speeds and proliferation of numerical simulation software consolidates the efforts of scientists worldwide for in-depth investigation of technological applications of laser material processing. Various computational techniques and their combination are used for this purpose, including "classic" single-parameter simulations, numerical experiments to black-box techniques and modern sophisticated algorithms.

Industrial application of technological processes of gas-powder laser cladding significantly depends on the following technological factors: laser beam characteristics, thermal and physical properties of cladding powder and processed workpiece, working parameters of powder feeding systems, focusing of gas-powder stream, type of assist gases and many other. Therefore, it is very complicated to establish science-based optimal [2] processing regimes and to develop powder delivery systems only by means of numerical computation.

Given that laser cladding could be described by adequate physical model that includes all non-linearities, the application of numerical procedures requires the generation of target function (maximum dimensions of clad or desired clad shape) and automatic adjustment of processing parameters, nozzles design etc. Changes to the design of technological equipment lead to changes in computational meshes and it is difficult to introduce automation to this process. Moreover, simulation and modeling of powder delivery systems and interaction of gas-powder streams with laser beam do not consider collisions between powder particles (which are of probabilistic nature)

At low powder flow rates, it is possible to obtain "perfect" gas-powder streams but its "harmony" breaks rapidly as powder particles mass flow rate increases. It is possible to adjust processing regimes by increasing laser power, mutual position of workpiece, laser beam and gas-powder stream to increase cladding efficiency and to minimize cladding defects. Although, the area of gas-powder stream cross-section changes faster that laser beam power density and required processing results could be obtained only with small changes to powder mass flow rate (Fig.1).

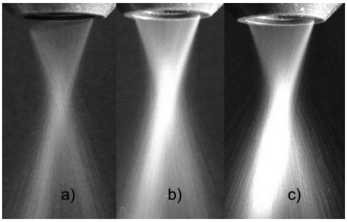


Fig. 1. Gas-powder streams at coaxial laser cladding with different powder mass flow rates, where (a) PMFR – 5 g/min; (b) PMFR – 15 g/min; (c) PMFR – 25 g/min.

The increase in productivity and quality of gas-powder laser cladding at high powder flowrates could be achieved with multi-channel nozzle systems [3, 4] or with more complex coaxial nozzle systems that generate additional protective gas stream that surrounds gas-powder jet [5]. First systems limit the gas-powder stream scattering at the nozzle exit, the other ones do the same but in space closer to the workpiece.

Multi-channel nozzles are more economically efficient. One of the benefits of these nozzles is that they could be used for laser cladding with lasers that generate laser beam with different cross-section – circular or rectangular.

The simplest way of gas-powder stream generation in the coaxial industrial laser systems is to use many powder supply channels that are positioned at certain angle to the workpiece. In this case, it is possible to use standard elements for the nozzle manufacturing, adjust powder channels individually etc. Moreover, it is possible to design powder supply channel with a ring-shaped protective gas stream around the gas-powder stream. Since the ring width is only 0.1-0.5 mm, this technique of gas-powder stream shaping is more economically efficient but it significantly increases the overall dimensions of the nozzle for laser cladding

In Fig.2 it is shown how three gas-powder streams exit cylindrical gas-powder supply channels and form a "focusing spot" at some distance from the nozzles exit. With the increase of the number of powder supply channels of the same inner diameter (at given value of powder mass flow rate, carrier gas mass flow rate etc.), the speed of gas-powder streams decreases, thus influencing the shape of gas-powder stream.

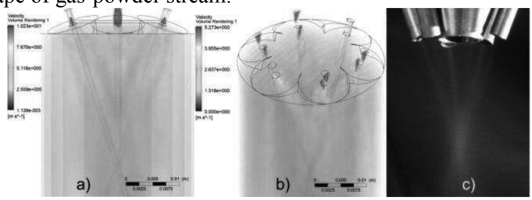


Fig. 2. Simulation of gas-powder stream propagation for different numbers of powder supply channels, where: a) 3-channel nozzle; b) 6-channel nozzles c) shape of gas-powder stream formed by 6-channel nozzle. Powder mass flow rate in all cases was set to 25 g/min.

It is worth to note that application of multi-channel nozzles guarantees greater productivity of technological processes comparing to other powder delivery nozzles. This is mainly caused by:

- smaller area of "focusing spot" of gas-powder jet formed by multi-channel nozzles;
- multi-jet nozzles are less influenced by fluctuations or changes in powder mass flow rate;
- the efficiency of powder usage in laser cladding is higher for multi-channel nozzles.

When high power diode lasers (HPDL) with rectangular laser beam focal spot are used for laser cladding, the formation of cladding layer of a given height depends on the angle a between the laser beam velocity vector and laser beam main symmetry axis. Gas-powder stream exits flat slot nozzle with some expansion angle and its behavior is similar to gas-powder stream that exits coaxial conical nozzle. However, due to the lack of circular symmetry we have two angles in mutually perpendicular planes, and gas-powder stream itself reminds a truncated pyramid (Fig.3).

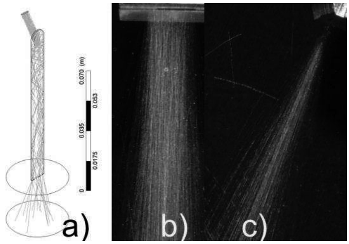


Fig. 3. Gas-powder stream profile (powder mass flow rate 10g/min) after the flat slot nozzle, where: a) – calculated trajectory of particles, b)-trajectory along the greater symmetry axis of laser beam (OX); c) – trajectory along the greater symmetry axis of laser beam (OY)

As well as for the conical nozzles, the influence of changes in powder mass flow rate on the profile of gas-powder stream could be reduced by the increase of the cross-section area of the flat nozzle or by the increase in the number of powder supply channels or nozzles. Therefore, if two powder supply nozzles are positioned symmetrically to laser beam this problem could be solved easily. Fig. 4 shows gas-powder streams from two flat nozzles for the aggregated mass flow rates of 10 g/min and 40 g/min.

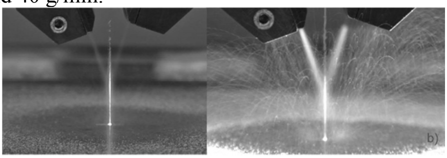


Fig. 4. Gas-powder streams from two flat nozzles for the aggregated mass flow rates of 10 g/min (a) and 40 g/min (b)

It is possible, at the design stage, to divide gas-powder stream into separate streams within the powder delivery nozzle [6], and these streams could be parallel to each other or they could converge at some angle thus minimizing the divergence angle of gas-powder stream at the nozzle exit.

Therefore, for a given powder mass flow rate all changes in HOC and the shape of laser clad (Fig.5) are caused by variations in powder density distribution in the interaction zone of focused laser beam and “focused” gas-powder stream. The efficiency of the chain powder – nozzle - laser beam – cladding layer could be evaluated by the area of the cross-section of clad layer.

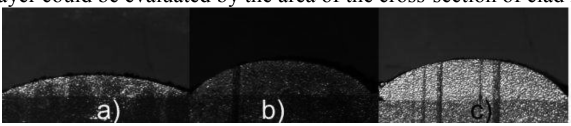


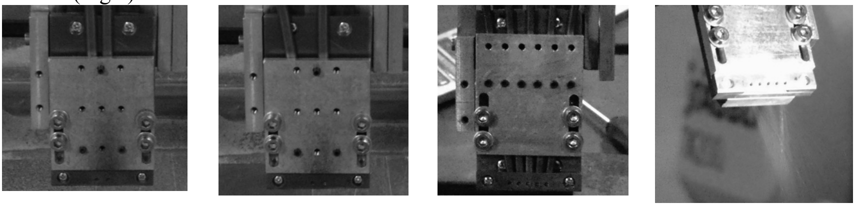
Fig. 5. Cross sections of clads, obtained with nozzles of different configurations (PMFR – 40 g/min, V –20 mm/min), where: a) ordinary flat nozzle; b) nozzle with splitter and converging powder supply channels inside the nozzle body, c) nozzle with splitter and parallel powder supply channels inside the nozzle body

Thus, for clads shown in Fig. 5, the area of cross-section doubles (Fig.5a and Fig.5c) when laser cladding is done with the flat nozzle where powder supply channel is split in two inside the nozzle body.

While comparing the performance of single- or multi-channel nozzles with equal overall cross-section area for given processing regimes it was noted that the synergy of components in nozzle-gas-powder stream-laser beam-workpiece system for multichannel nozzles makes greater contribution to the formation of clad layer.

All these observations led to the designs of powder delivery nozzles that have the following features:

- ability to alter angles between the nozzle channels;
- vary the number of connected powder supply channels;
- deliver different powder mixtures simultaneously, given there are several powder feeders available (Fig.6).



a) b) c) d)

Fig.6. Multi-channel nozzles or gas-powder streams delivery, where: a), b) – two channel nozzle with symmetrical (a) and asymmetric (b) channel set-up; c)– general view of five channel nozzle, d) powder streams from three central channels of five channel nozzle

The simplicity of angle altering is in the ability of each channel to rotate around an axis that is located near the nozzle exit and every channel is confined in and rotated by a moving slider. The nozzle also has a water-cooled body for the efficient heat dissipation while operating.

Multi-channel nozzles for gas-powder delivery into the processing zone increase the productivity of technological processes of laser cladding and could be used for both circular and rectangular focusing laser spots. Multi-channel nozzle systems provide the user with numerous configurations that could improve the uniformity of cladded layer.

Конструкції багатоканальних сопел для операцій лазерної наплавки

Жук Р.О.; Анякін М.І.; Цинлі Занг, Жиюн Чен

Анотація: *Робота присвячена дослідженню технологічного процесу лазерної газопорошкової наплавки з використанням потужних діодних та коаксиальних волоконних лазерних систем. Основна увага в роботі присвячена вивченню спільного впливу параметрів сфокусованого газопорошкового струменя і сфокусованого лазерного випромінювання на властивості наплавленого шару (розміри, форма і т.д.). Дослідження процесу виконувалося по ряду напрямків: чисельного моделювання процесу фокусування газопорошкової суміші соплами різної конфігурації; експериментальної перевірки результатів чисельного моделювання, шляхом обробки та аналізу відео зображень віддзеркаленого, від порошинок, променю допоміжного лазера; безпосереднього дослідження впливу режимів обробки на властивості наплавленого шару. Встановлено, що використання багатоканальних систем постачання газопорошкової суміші в зону дії сфокусованого лазерного випромінювання дозволяє впливати як на продуктивність так і якість обробки.*

Ключові слова: *лазерна газопорошкова наплавка; сопло*

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