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Laser Powder Technology for Cladding and Welding

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Laser powder technology offers several advantages compared to conventional cladding and welding techniques and is attracting increasing industrial interest. The laser materials processing group of the German Aerospace Center at Stuttgart, Germany, is currently developing these new methods for application in industrial process engineering. Key areas of the work include the design and implementation of a modular working head that can be universally used for laser welding and surface treatment, the development of powder nozzles for cladding and welding, and the construction of new systems for special applications (e.g., for inner cladding). Some of these developments are described, as well as some important examples that highlight the potential of welding and surface treatment using laser powder techniques.

Keywords cladding, laser powder technology, light alloys, modular working system, wear resistance, welding

1. Introduction

Cylinder heads, gear units, crank cases, and chassis are all parts of automobiles, predominantly made of light alloys like aluminum and magnesium. Although the density of these materials allows considerable savings in weight and, hence fuel, in most cases it is necessary to modify the basic form of the metal. This can be done either by surface treatment or by welding (Ref 1-7).

Cladding is used to increase the hardness of a component or to improve the corrosion and/or the wear resistance of the surface. There are many technologies available to do this (e.g., thermal spraying, electroplating, physical vapor deposition, etc.). Most of these conventional techniques are limited by a maximum coating thickness of less than 0.5 mm. In contrast the maximum thickness achievable by laser surface treatment is on the order of several millimeters. Moreover, the bonding between the coating and the substrate is excellent, and the tendency to form pores and cracks is also reduced. Furthermore, cladding is not only limited to light alloys, but can also be used for materials such as copper and steel.

The same laser processing system can easily be used for welding and surface treatment by modifying the working distance (Fig. 1). This is especially useful for aluminum parts. The process always needs additional material, which is normally supplied in wire form. A new process called laser powder welding replaces the traditional wire with a wirelike focused powder beam and extends the use of lasers in welding applications.

With the help of some examples that have already been transferred to the automobile industry, this article aims to demonstrate the application of welding and surface treatment using laser powder technology.

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2. Process Equipment

Laser powder technology basically comprises five elements (Fig. 1): a high-power laser, a beam-guiding system including the focussing optics, a powder supply system, a cladding/welding module, and a manipulator to handle the workpiece. Today the only laser systems that are capable of supplying a continuous wave (cw), with constant emission of radiation of power of several kilowatts, are solid-state and CO_2 lasers. The results discussed in the following sections were obtained using either a Nd:YAG laser (3 kW), a CO_2 slab laser (2.5 kW), or one of two fast axial-flow CO_2 lasers (4 kW, 20 kW). Different kinds of commercially available powder supply systems were used (e.g., Metco MFP1, Metco MFP2 (Sulzer-Metco, Westbury, NY), Plasmatechnik Twin 10-C). The workpieces were manipulated by either a fixed working station (either a four- or a six-axis system) or a seven-axis robot system.

3. Laser Powder Technology

The correct combination of focussing optics and powder supply is essential for a successful cladding or welding process. Normally a high focal length is chosen to increase the depth of focus (or “Rayleigh length”) of the focussing optics, as this is advantageous for processing uneven surfaces. Additionally, the optical elements are better protected against powder pollution at longer working distances. However, the choice of the focal length often depends on the component to be processed. For welding and outer cladding at $\lambda = 10.600$ nm a copper mirror with a focal length of $f = 300$ mm was used, while the standard optics at $\lambda = 1.060$ nm was a quartz lens with $f = 140$ mm. In contrast a focal length of $f = 43$ mm was necessary for the inner cladding of tubes at $\lambda = 1.060$ nm to allow a compact “lance” construction (see Fig. 2). A carrier gas was required to transport the powder homogeneously over longer distances. Generally speaking, the greater the distance is between feeder and lance, the greater the gas requirements. Furthermore, to obtain good cladding or welding results, it is usually necessary to separate the powder and the carrier gas after transportation to the lance. For this reason a powder-gas separator, a so-called cyclone, was developed at DLR and optimized as part of the cladding/welding module.

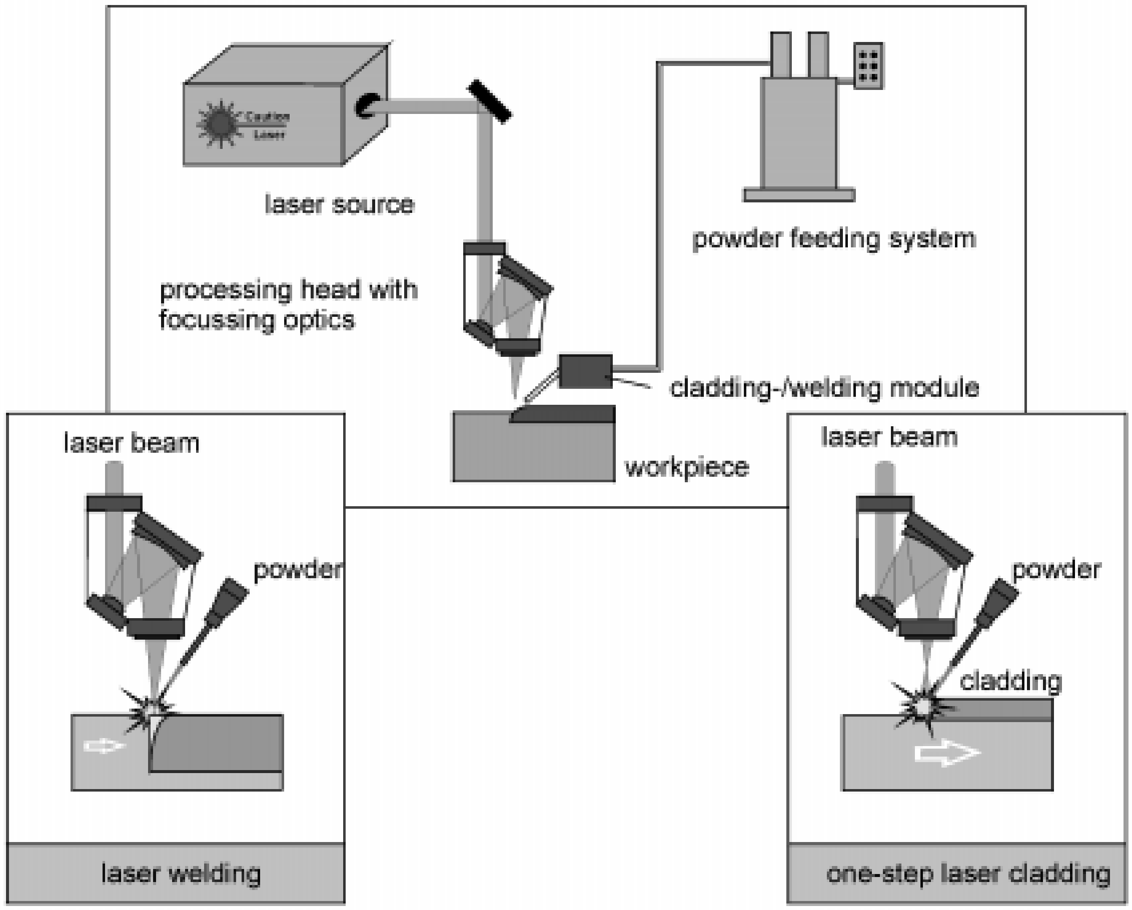

Fig. 1 Laser beam technologies with powder addition

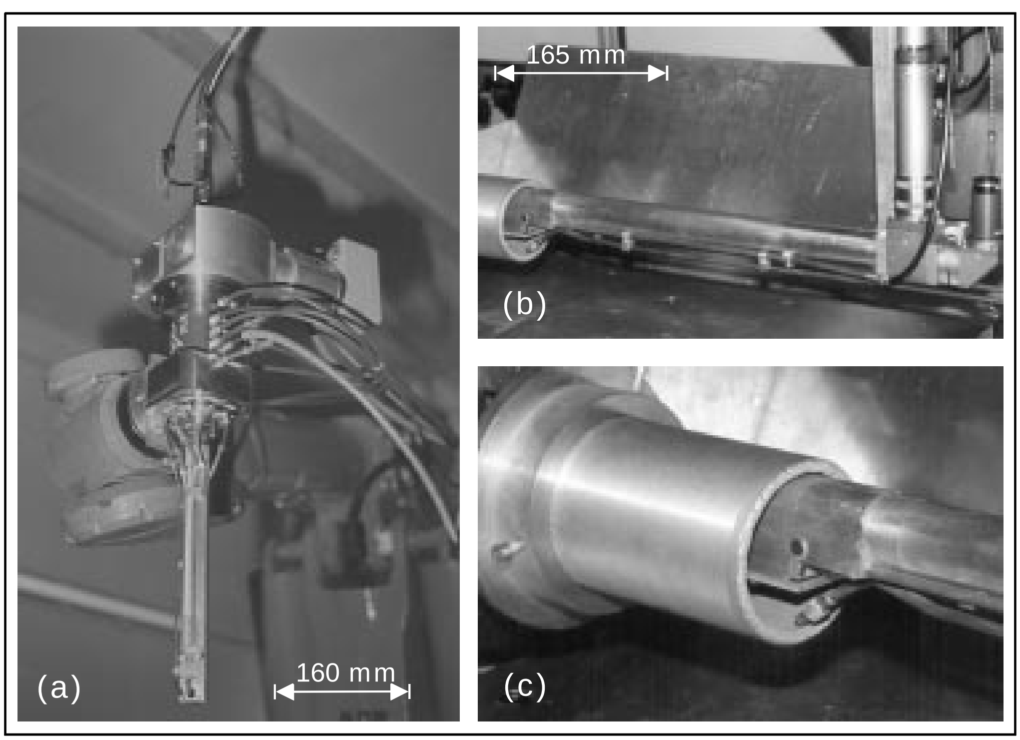

Fig. 2 Laser powder processing of inner surfaces. (a) Rotating lance fixed to a moving robot. (b) Moving component. (c) Stationary lance

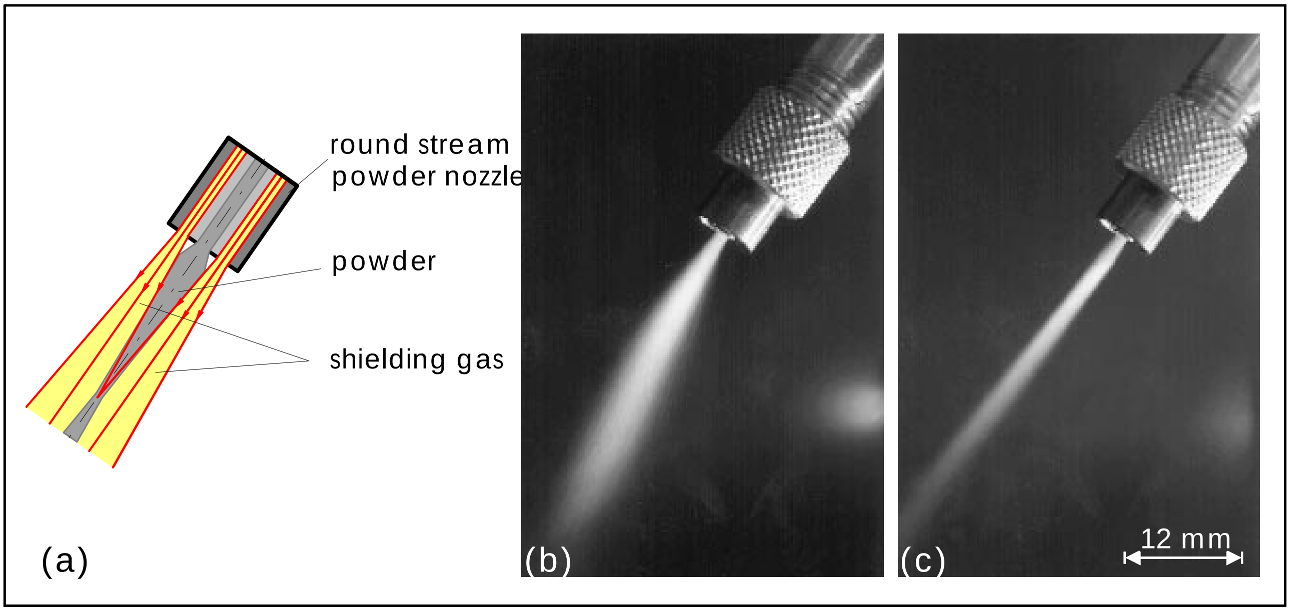

Fig. 3 Influence of the shielding gas on powder focussing. (a) Scheme. (b) Round-stream powder nozzle, gas switched off. (c) Round-stream powder nozzle, gas switched on

Additionally most welding or cladding processes employ a shielding gas. Apart from its main task of protecting the working area from oxidation, the shielding gas also helps to focus the powder stream (Fig. 3). All of the round-stream powder nozzles that were used for longer working distances include an integrated shielding gas system. This results in a compact, modular design and increases the flexibility, particularly at difficult to reach working positions.

Figure 3(a) shows the mode of operation. Without shielding gas the powder diverges rapidly (Fig. 3b), but is formed into a jet or beam with gas assistance (Fig. 3c). Up to now it has been possible to produce a powder jet with a maximum length of 30 mm. If there is a perfect alignment between powder and laser beam, powder deposition efficiencies of up to 90% can be achieved. Figure 4 shows a possible alignment tool. Here a cladding and welding module has been mechanically fixed to the focussing optics of a Nd:YAG laser, thus allowing a correlation of the focal point of the laser and the point of powder impact.

This flexible module can easily handle many accessible contours, but a different configuration is required for the laser coating of the inner surfaces of tubes and cylinders, etc. Such a system was developed at DLR and is known as a rotating lance for inner cladding. Two different arrangements can be distinguished (Fig. 2): (a) a rotating and/or linearly moving component with a stationary lance and (b) a rotating lance attached to a moving robot with a static component.

Although the minimum internal diameter that can be used in both cases is approximately 80 mm, the scope of the two arrangements differs quite significantly. In the first case there are no major demands placed on the cladding process itself, as there is no change in the cladding direction; that is, no overhead cladding. The second case, however, offers more flexibility, especially if heavy components need to be processed. Additionally the combination robot/rotating lance can be integrated more easily into a production line. Some typical examples suitable for mass production are described in the following sections.

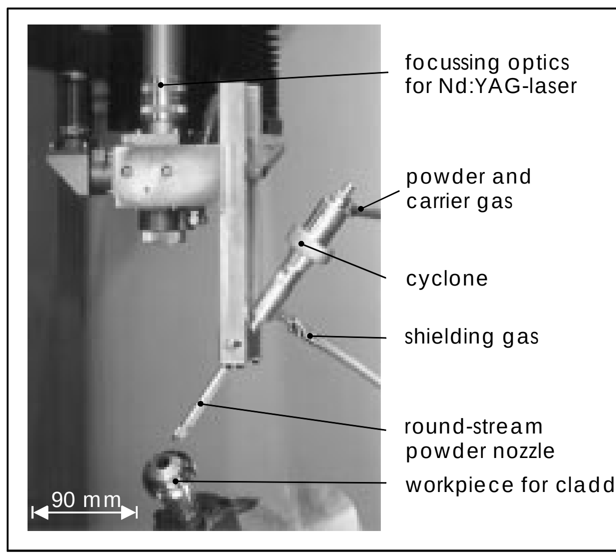

Fig. 4 Cladding and welding module

4. Surface Treatment

The choice of substrate materials that can be coated by laser powder technology includes steel, cast iron, copper, aluminum, and magnesium. The coating powders that are used are classified into aluminum, iron, nickel, and cobalt-base alloys. Titanium carbide, tungsten carbide, or silicon carbide can be added to these alloys to increase the hardness.

During laser cladding the bulk of the powder interacts with the laser beam before reaching the surface of the workpiece. The energy of the laser beam is partially absorbed by the powder, depending on the powder composition, particle size, and powder density. At $\lambda = 1.064$ nm, typical absorption coefficients for a spherical particle are up to 38% for iron, 7% for aluminum, and 2% for copper (Ref 8). The residual laser energy that is neither absorbed nor scattered by the particles hits the substrate surface, where it is dissipated by reflection or absorbed, resulting in the melting of a thin surface layer.

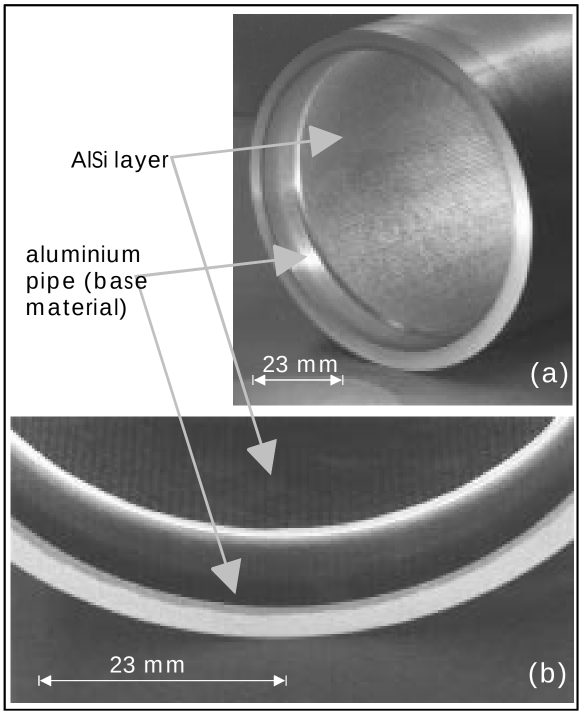

Fig. 5 (a) Inside cladding of an aluminum pipe with hypereutectic AlSi (Nd:YAG laser power 3 kW, processing speed 1.5 m/min). (b) Enlargement of the front part of the pipe

The laser coating process is especially suitable for aluminum because any precleaning such as etching of the aluminum surface layer is not necessary. The inner cladding of a hypereutectical AlSi layer (thickness: ~2 mm) on an aluminum pipe (AlSi10 cast) is depicted in Fig. 5(a). The enlargement (Fig. 5b) shows explicitly the axial overlapping of the adjacent coating tracks (δ ~45%) and the homogeneous structure of the layer. After final processing of such pipes by milling or honing they can be typically used as liners.

Figure 6 shows other industrial applications. Wear resistant layers have been applied to aluminum substrates as valve seats (Fig. 6a-c) and to piston-ring grooves (Fig. 6d). In the latter case, the individual steps are described in detail. After machining an oversized groove (1), it was filled by laser cladding (2). The final piston ring groove was machined (3) to produce the final geometry required.

The same approach can also be applied to pistons made of magnesium, but this requires the use of slightly modified working parameters. Besides aluminum and magnesium, there are also other base materials that can be finished by laser power technology. Figure 7 shows a nozzle made of continuous cast copper, which has been partially clad with a nickel-base alloy. Using a laser power of 11 kW ($\lambda = 10.600$ nm) the extent of mixing between the alloy and the copper is less than 5%.

Figure 8 shows another example of the use of laser powder technology. The nozzle of a die-casting machine that is exposed to large alternating mechanical and thermal loads has been clad with Stellite 157, a cobalt-base alloy, using a Nd:YAG laser

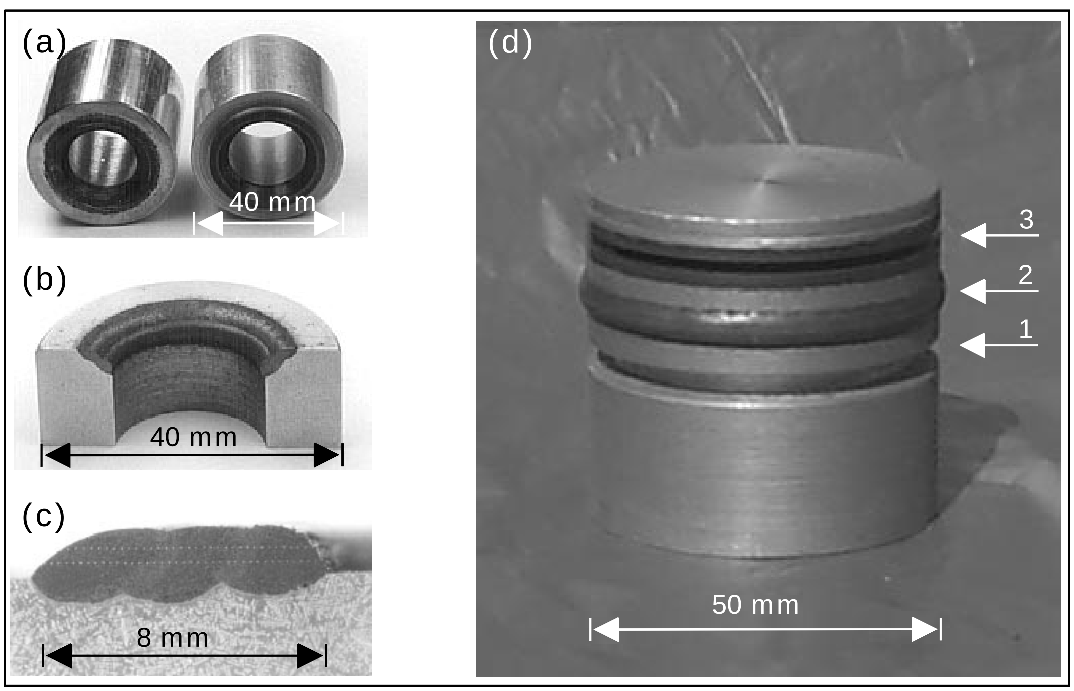

Fig. 6 (a) to (c) Valve seat cladding with Al-Si-Cu-Ni powder (CO_2 laser power 6.8 kW, processing speed 0.6 m/min). (d) Piston-ring groove processing with Al-Si-Ni-Cu powder (Nd:YAG laser power 2.7 kW, processing speed 0.65 m/min). 1, oversized groove; 2, filled by laser cladding; 3, final machining

power at 2.5 kW. Although this mainly serves to increase the abrasion resistance of the nozzle and, hence, to reduce the down time of the die-casting machine, the same process can also be used to repair damaged nozzles. This is an additional benefit of laser cladding because in contrast to other coating techniques, material can be applied exactly to those areas where it is required.

5. Welding

In general, the advantages of laser welding in industrial process engineering are manifold. Particularly important are a high welding speed, a high degree of flexibility, and automation, as well as a reduced distortion of the components because of a low heat absorption. Conversely, the investment costs of a laser system and the requirements regarding process accuracy are both high. However, the laser powder technology offers some promising starting points, particularly with regard to precision.

Figure 9 shows the process of step welding and some typical aluminum welding applications on car bodywork and on a car roof. Step welding can be performed easily with laser powder technology, while it is difficult to obtain such good results using laser welding with wire. One of the main problems of stepwelding using a wire is the moment the laser stops. In most cases the wire is welded immediately to the workpiece, leading to a failure of the process. Although new pull-and-push systems increase the reliability of welding with wire, this effect is totally unknown to laser powder welding.

Finally, Fig. 10 presents an application outside the motor industry. Here the overlap welding of a saw blade made of high-speed steel can be seen. The saw blade itself (100 mm diameter,

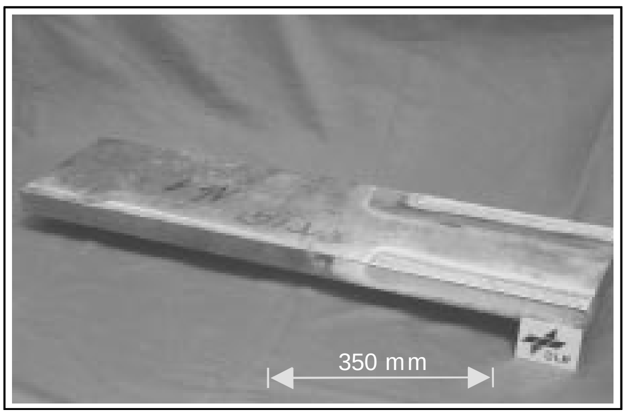

Fig. 7 Two wear resistant layers made of a nickel-base alloy deposited on a copper substrate (CO_2 laser power 11 kW)

Fig. 8 Nozzle of a spray die-casting machine made of hot work tool steel (1.2343) coated with a cobalt-base alloy (Stellite 157)

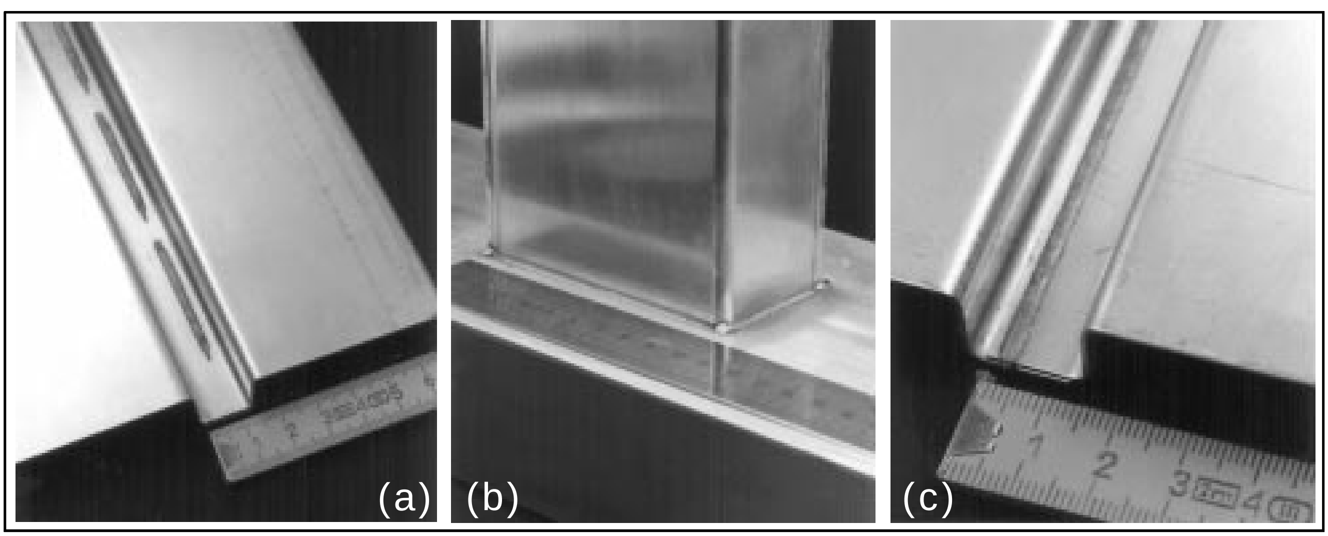

Fig. 9 Typical welding applications in the motor industry using a Nd:YAG laser power at 3 kW. (a) Step welding (working speed 4.5 m/min). (b) Fillet welding of the car body structure (3.3 m/min). (c) Overlap welding of car roof parts (4.5 m/min)

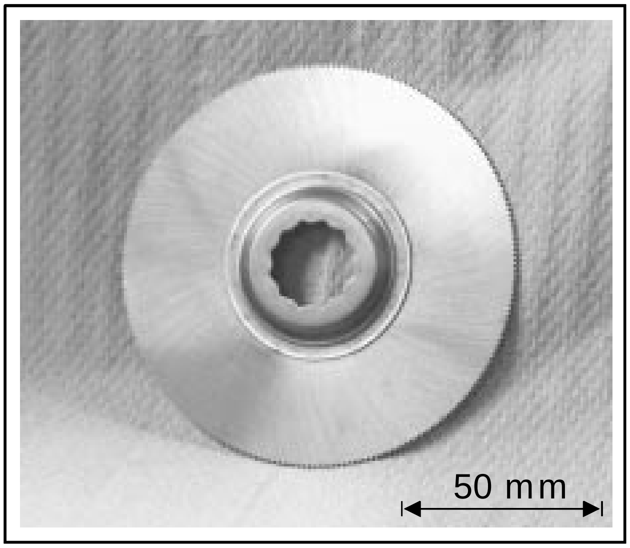

Fig. 10 Overlap welding of a saw blade made of high-speed steel

depressed center) is attached subsequently to an oscillating cutter. This tool can be used to cut sheet metals up to 1 mm thick, glazier putty, wood up to 30 mm, and other materials. Typical applications include car body repairs, removing wood door frames, cutting out glass panes, separating metal trims from windows, etc. To prevent the blade from thermal deformation, only a very small amount of an iron-base alloy (stainless steel powder Metco 41C, Sulzer-Metco, Westbury, NY) can be used. The same is true for the power of the Nd:YAG laser, which is between 0.5 and 1 kW.

6. Conclusions

Specially designed nozzles offer the possibility of forming and guiding powders into a precise jet or beam, analogous to the wires used in traditional thermal spraying. This leads to a high powder efficiency and allows access to positions that are normally difficult to weld or clad evenly. Several significant applications in the automobile industry highlight the potential of the powder technique in the areas of welding and surface treatment. In the future, this technology will also find application in other branches of engineering, for example, in the aircraft and machine-tool industries.

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