Toby Strite, Andreas Gusenko, Michael Grupp, Tony Hoult

Multiple Laser Beam Material Processing

Abstract: Technological processes such as welding, braze welding or surface treatment utilising single-spot laser beams as welding power sources are well known and commonly applied. The improvement of technological processes and quality of treatment are subjects of research in terms of new laser welding technologies. The article presents attempted applications of several laser beams having various parameters in the braze welding of car body sheets, the welding of Al-Si-coated high strength steels and in the making of polymer-metal joints.

Keywords: laser welding, braze welding, laser beam, Al-Si coated steels

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Lasers are an indispensable material processing tool for manufacturers spanning from heavy industry to consumer electronics. Most view laser material processing as a mature, well understood productivity enhancement which manufacturers constantly seek to extend to new segments of their business. Of late, that search has produced a fascinating trend towards the deployment of multiple laser beams on a single workpiece, each optimized to perform a facet of the overall process. This article highlights three examples of multiple laser beam processing. Trifocal brazing utilizes coordinated beams to join automotive materials with high strength and superior cosmetics. Next, we examine the benefits of a two-step welding process for high strength steel in which a laser cleaning step enables laser welds of outstanding strength and integrity. Our final example highlights how laser surface texturing of a metal enables high strength hermetic polymer to metal bonding. These examples highlight the rich possibilities available when multiple laser beams of differing diameter, pulse durations or even wavelength are coordinated to produce previously unobtainable results.

Trifocal Brazing

The automobile industry relies on the unique ability of lasers to provide high joint strength with minimum material usage, while at the same time promoting safety and fuel economy. While laser welding is entrenched within the automobile manufacturing, a more cosmetic process is preferred in visible joints along the roofline and car sides. In contrast to welding, brazing is a technique that does not melt the surfaces to be joined. Rather, for automotive applications, laser energy melts a wire to form a cohesive joint between two steel or aluminum surfaces. Automakers desire a brazing process which requires just a light brushing

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prior to the application of paint to realize a truly seamless joint.

Brazing studies on electro-galvanized low--carbon steel link joint quality and aesthetics to edge variability. In particular, oxides and contaminants residing on the thin Zn anti-scaling layer are the main causes of spatter and edge roughness. This knowledge inspired the development of a novel 3-beam brazing system in which two lead beams travel along the steel edges to ablate contaminants and pre-heat the Zn surface layer to promote wetting. The powerful trailing beam supplies energy to melt the Cu/Si wire to seamlessly join the newly cleaned steel surfaces as shown in Figure 1.

The trifocal brazing system relies on the flexibility of fiber technology as illustrated in Figure 2. Fiber lasers are coupled into three optical fibers of different diameter which are delivered through a single cable. Near the workpiece, the delivery optic creates the desired 3-beam profile allowing the narrow lead beams to pre-clean

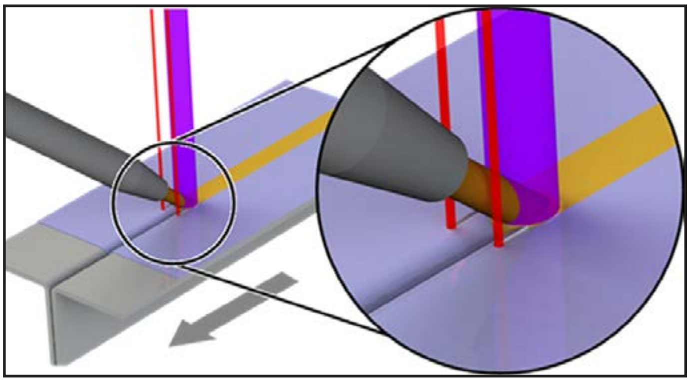

Fig. 1. Schematic of trifocal brazing. Two lead beams (red) clean and pre-heat the steel edge surfaces to promote wetting. The powerful trailing beam (purple) melts the Cu/Si wire to form a seamless brazed joint which, after painting, can be invisible to the naked eye.

prior to the trailing beam completing the spatter-free brazed seam.

To directly assess the benefits of trifocal brazing, a near infrared fiber laser was used to join a series of 0.8mm hot-dipped steel samples using 1.6 mm CuSi3 alloy wire with a 3.5kW infrared brazing beam at a process rate of 4.5 meters per minute. When 350W lead beams are added to pre-clean the steel edges prior to melting the Cu/Si wire, greater edge uniformity and a better surface finish are readily observable (Figure 3).

Trifocal brazing combines cleaning and joining in a single process, greatly reducing post-processing requirements before painting. The brazing can be fully automated at high speed with outstanding joint strength and excellent reproducibility along straight and curved borders. Automakers are increasingly adopting trifocal brazing as their preferred solution for cosmetic steel joints to optimize both productivity and aesthetics.

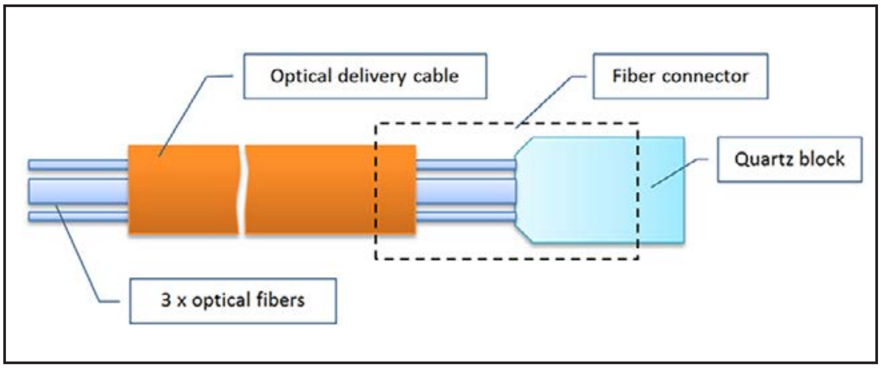

Fig. 2. Three fiber core trifocal brazing optics. Specially engineered optics enable different diameter fibers to pass through a single process fiber to deliver spatially offset spots of different size to the brazing area.

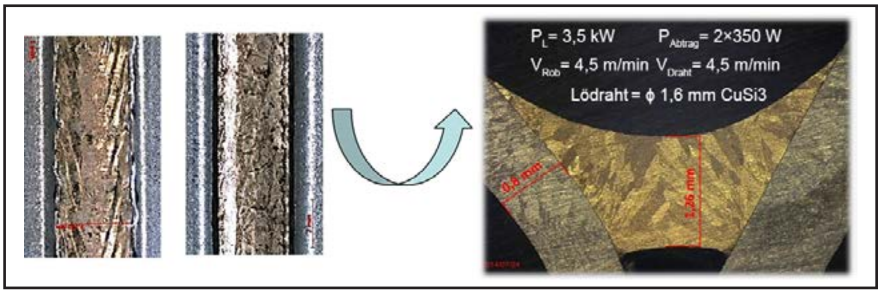

Figure 3. Comparison of single-spot and trifocal seam brazing. Single spot (a) and trifocal (b) brazed seams joining steel with Cu/Si wire. An improved finish and suppression of edge roughness is evident in the trifocal brazing example. A cross-section (c) highlights the joint uniformity and quality obtainable with trifocal brazing.

Two-step Laser Welding of High Strength Steel

Automakers relentlessly seek materials and joining methods which enable safer and more efficient vehicles. High strength steels (Hss) bolstered by the element Boron have moved to the forefront of automotive innovation offering strength levels so great that the "Jaws of Life" auto rescue tool had to be re-specified in North America. Higher strength presents the opportunity to use less material for reduced vehicle weight assuming joining technology can keep pace. Laser welding is automakers' preferred method for joining HSS. Early efforts were hampered by the AlSi protective coatings added to avoid scaling during the hot stamping process. Brittle Fe-Al inter-metallic layers may result when AlSi-coated HSS is laser welded.

Outstanding HSS weld quality is achievable when the anti-scaling coating on either side of the weld region is laser ablated, enabling a weld between identical, clean steel surfaces free of Fe-Al inter-metallics. Figure 4 illustrates a clean steel surface prepared by laser ablation on which the AlSi coating is fully removed by a 1 kW, 70ns near infrared pulsed fiber laser. The ablation laser provides up to 100mJ pulse energy (7-10 J/cm^2 fluence over a 1 mm^2 spot) delivered through a novel square process fiber to perform a precise and economical 10m/min ablation of a 30µm AlSi coating. Subsequent high speed welding using a multi-kW continuous wave (CW) near infrared fiber laser completes the joining process allowing strong, but lightweight tailor-welded blanks to be supplied to the auto industry.

In contrast to trifocal brazing which employs two CW laser beams of different diameter, two-step welding of HSS is optimized by first applying a high energy pulsed nanosecond ablation laser followed by a high power CW welding laser. Our final example also utilizes a pulsed/CW laser one-two punch, but we extend into the sub-ns pulsed regime and apply two different laser wavelengths.

Polymer to Metal Joining

Welding requires melting of opposing surfaces in order to fuse the materials into a robust joint. Welding is widely used to join metals to metals, or polymers to polymers. However, disparate melting temperatures largely rule out polymer to metal welding. Effective polymer to metal joining remains a hotly sought technology for industries as diverse as consumer electronics to medical devices. A recently developed two-step process relying on new fiber laser technology provides a promising solution.

Figure 4. Laser Ablation of AlSi coating for high-strength steel welding. High pulse energy fiber laser technology delivered through a novel square fiber efficiently ablates the AlSi coating to expose the native steel surface for enhanced weld quality.

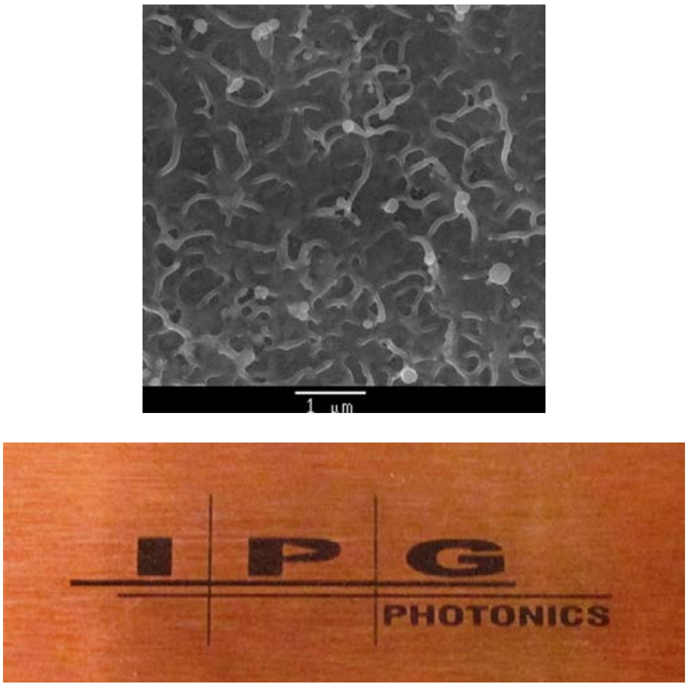

Fig. 5. Copper surfaces textured by a sub-nanosecond fiber laser. (a) Example of the fine, nodular Cu surface structure (10,000x magnification) obtained using a sub-ns near infrared fiber laser. (b) The textured Cu surface is perfectly black, making it an ideal absorber for subsequent laser processing.

The first step relies on a 30 W near infrared fiber laser capable of 400 kW peak power when pulsed at 150ps to provide a novel metal surface texture (Figure 5a). Microscopic studies suggest the high laser fluence melts a nanometer scale surface layer which coalesces quickly into a fine, nodular structure, one whose large surface area is ideal for subsequent adhesive bonding. What is remarkable about these textured surfaces is that they can be made perfectly black, even on highly reflective metals like Copper (Figure 5b). Experienced welders know that a uniformly dark surface provides the widest process window, since reflectivity variations affect the threshold energy a laser must supply to couple into a reflective metal.

Polymer-to-metal joining relies on the 1.9um lasing wavelength of Thulium-doped CW fiber lasers. The mid-infrared wavelength is more strongly absorbed by common transparent polymers than near infrared fiber laser or diode laser sources. Conventional 1um lasers pass through the polymer, heating only the opposing metal surface, which conducts heat into the polymer, eventually melting it into the metal to form a weak bond. We find that polymer to metal bond strength is remarkably improved by first texturing and darkening the metal surface, then applying thermal energy using the 1.9um fiber laser. The longer wavelength transfers heat directly to the polymer as well as the polymer to metal interface. The direct heating of the polymer combined with the dark nodular metal surface provides ideal bonding conditions. We have formed polymer to Titanium bonds which are hermetic and so strong they fail in the polymer when subjected to shear force. In contrast, when the surface texturing step is omitted, lap shear tests fail at the polymer to metal interface, attesting to a weaker bond. Robust, hermetic joining of transparent polymers to metals opens a new degree of design and manufacturing freedom which has already generated interest among customers in fields as diverse as medical devices, consumer electronics and low-cost consumer products.

Conclusions

So, where one laser is good, two or more laser beams working in concert can be even better. Lasers of different spot sizes, pulse durations or even different wavelengths can be combined into a single process to realize superior results that are unobtainable with any single laser. Multiple laser beam processing is already undergoing rapid adoption in automotive manufacturing, but we believe this is only the beginning of a powerful new trend.