Laser Welding P/M
For Automotive Applications

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ABSTRACT

The ability to laser weld automotive components is a determining factor in converting the currently specified wrought or cast materials to powder metallurgy (P/M) parts for various applications. Material selection, process conditions and joint design are known to have a significant influence when fusion welding P/M components. Welding trials were conducted to determine the appropriate laser parameters for several P/M grades at various density levels. Bead-on-plate, overlap and butt joint designs were attempted, primarily without filler metal additions.

INTRODUCTION

Laser welding has gained considerable acceptance in the automotive industry because it provides several advantages over other joining processes. Benefits include high productivity, good flexibility, and low maintenance and energy costs along with the ability to produce strong welds. Automatic transmission applications are particularly well suited to the laser joining process. All major U.S. automobile manufacturers are currently laser welding automatic transmission components to meet production requirements· Additional economic and engineering benefits could be realized by converting several of these existing transmission components to P/M parts.

Previous investigations involving P/M laser welding found the process had merit, but some difficulties were encountered. Oxides, residual gas levels or impurities associated with the sintering process can promote blowholes or weld porosity because these constituents tend to absorb greater amounts of laser radiation which results in overheating[2]· Additionally, P/M materials with medium to high carbon levels or low-alloy grades with greater hardenability could not be successfully welded without filler metal[s].

Joint selection is a critical aspect of any weldment's design particularly when it involves the unique characteristics associated with P/M parts. Bead-on-plate (BOP) welds are primarily used to evaluate P/M laser weld quality. This technique is not used on production parts and does not take into consideration the densification, which occurs in the weld zone of P/M materials. To assess the effects of joint design, the investigation-included overlap and butt joints using low carbon steel to join several P/M base materials.

Welding trials were conducted at Rofin-Sinar to determine the appropriate welding parameters required to successfully joining P/M parts. The effects of part density and process conditions were evaluated in terms of how each potentially influences weld quality. All efforts attempted to focus on the practical aspects of welding in a high production environment using existing laser and P/M technology.

LASER WELDING IN THE AUTOMOTIVE INDUSTRY

The majority of high power laser welding installations in the automotive industry consists of cross flow CO2 lasers in the power range of 3 kW to 5 kW. The laser beam is directed to the workstation and focused on the part by the use of copper mirrors. Weld depth and width depend on the process parameters, which are: laser power, speed, focuses spot size and position shield gas flow and direction. The laser weld is a non-contact process, an easily controlled tool, and well suited to automation or CNC systems. The possibility of switching the beam from one laser source to several workstations allows optimum use of the laser for a combination of assembly and welding functions. Inherent laser weld process flexibility helps satisfy automotive production requirements without extensive set up for different part geometries.

Laser welds show fairly narrow cross sections and therefore require parts to be precisely manufactured and positioned. Low heat input and thermal distortion reduce secondary machining requirements. The process is also capable of welding a variety of joint configurations and material combinations.

WELDABILITY OF P/M COMPONENTS

Powder metallurgy technology is unique in regards to the types of materials and process conditions used to manufacture various parts. P/M performance characteristics are achieved through a combination of finished density, alloy composition and part microstructure. These factors provide considerable flexibility when designing to meet specific application requirements. This same flexibility is also available for determining the various aspects of P/M weldability.

Density has a pronounced influence on both performance and weldability. Porosity affects thermal conductivity by acting as a thermal insulator, which retains heat. This condition is commonly offset when using conventional arc welding processes by lowering the heat energy input. However, in laser welding a high-energy beam heats by radiation, whereas conventional arc processes heat by conduction. Previous investigations have not determined how porosity and related thermal diffusivity characteristics influence the amount of absorbed radiation and overall weld parameters.

Presumably, high beam intensity would tend to vaporize metal particles distributed in a P/M matrix, whereas a denser cross section should respond similarly to wrought material. In contrast, and perhaps to some benefit, porosity reduces the depth of penetration and the material's overall hardenability by slowing the rate of cooling. This may somewhat offset other limiting characteristics associated with porosity by reducing the level of stress in the weld zone and help minimize martensite transformation in higher alloy grades.

Laser welding is generally an autogenous process, which establishes a joint without the use of filler metal. This places greater importance on the base materials to be joined for final control of weld metal chemistry and microstructure. Weld success rates subsequently become very dependent on base material quality.

Many factors are influential in determining overall weldability of P/M materials. Composition plays a major role in determining hardenability for a given density level. Higher alloy contents promote transformation to martensite and increase stress levels within the weld joint. This is particularly true for the high-energy focal point and narrow heat affected zone associated with laser welding. It has previously been identified that materials containing high sulfur and phosphorus levels promote weld defects and should be avoided. Sintering parameters that minimize residual gas levels, oxides or other possible contaminants should also be specified for welded parts. Additionally, pores within a P/M part can trap impurities and possibly influence weldability. Process conditions should include measures to prevent residual lubricants, coolants or oils from being entrapped in the pores or remaining oil the surface.

JOINT DESIGN FOR *P/M* LASER WELDING

Perhaps tile most important aspect associated with achieving a successful weld is proper joint design. This is particularly true when laser welding P/M components. When heat energy is supplied at sufficient levels to melt particles, densification occurs in the P/M weld metal. This volume change increases stress levels in the joint and may result in cracks, or materialize as voids, fissures or pipe formations within the weld metal. Proper joint design can minimize or compensate for shrinkage by reducing the amounts of *P/M* metal affected. Joint selection, beam positioning, power settings, travel speed, and P/M part design are all influential and should be considered ill the development stage to insure a successful weldment.

Powder metallurgy parts require special consideration to insure that weld gases (CO/ CO2 reactions) can be properly vented and don't become trapped in the weld metal. If this occurs, unacceptable levels of porosity will result. Weld techniques call minimizes porosity by increasing the time which gases have to dissipate through the molten weld puddle. Several parameters can be adjusted singularly or in combination to help exhaust contaminants and lower porosity, e.g. reduce weld speed, increase focal length or scan tile beam across tile joint.

Proper joint design should minimize induced stresses and provide sufficient pathways for vaporized materials to escape the weld zone. The examples in Figure 1 were reviewed by Fiat Auto Manufacturing Div. for laser welding high carbon materials[4]. Design A was found to have a greater likelihood of exhibiting weld porosity and significant levels of internal stress concentrations. The channel provided ill design B lessens the need for exacting fit-up dimensions typically required with attogenous laser welds. In addition, this joint configuration minimizes stress levels associated with high carbon materials by reducing the amount of material affected and providing multiple pathways for escaping gases. Design B could easily be incorporated as a P/M weldment, thereby eliminating the need for weld filler metal additions when joining higher alloy materials.

Trial conditions were established to better understand the relationship between part density, material composition (particularly carbon content), and joint design and laser parameters on tile integrity of the weld joint. In fill approach, guidelines useful for future application development programs will be established for part design and material selection.

Ring specimens used for the welding trials were conventionally processed by single pressing to nominal values of 6.8, 7.0 and 7.15 g/cm^3 density. Sintering at 1120°C for 45 minutes at temperature in a nitrogen - hydrogen atmosphere was conducted under production conditions. Two trial compositions believed to facilitate the laser welding process included MPIF / F-0005 with all actual 0.35% admixed graphite and FN-0205 with 0.5% graphite and 2.0% nickel.

Additional samples representing au FN-0400 and Ancorsteel 41 AB were also selected to determine the influence of their higher alloy content, ability to achieve elevated as-sintered strength levels and the significantly greater hardenability associated with Ancorsteel 41 AB. The latter material is a chromium, molybdenum, manganese, nickel bearing alloy that approximates a P/M version of AISI 4140/4340.Both materials were high temperature sintered at 1288° C in a nitrogen - hydrogen reducing atmosphere. Sintered densities for these materials were 7.30 and 7.05 g/cm^{S}, respectively. Powder forged PF-4650

Sample Chemical Analysis

	C	**N**	**O**	**Cr**	**Mn**	**Mo**	**Ni**
FN-0400	0.20	0.018	0.019		0.10		4.0
Ancorsteel <u>41 AB</u>	0.50	0.031	0.008	0.75	0.90	0.85	1.0

samples were included for comparison purposes. These samples also represent an application currently being considered as a potential conversion.

Laser welding parameters were established using a Rofin-Sinar RS-850I, CO2 laser set at either 5 kW or 3kW output power. Weld penetration attempted to maintain a constant 3 mm depth using 5 kW @ 3.7 m/min, or 3 kW @ 2.2 m/min, travel speed. Helium shielding gas was supplied transverse to the workpiece at 28 I/min. flow rate. Weld settings included a constant power mode with a focus on the surface of the workpiece.

Several joint designs were evaluated for the specified materials and density levels. Bead-on-plate welds were performed on all samples. Butt welds attempted to join a low carbon wrought AISI 1008 grade to various P/M materials including the higher alloy compositions. Overlap welds were also included using similar material combinations as the butt weld configurations. Butt and overlap weld samples, using a 0.3 mm thick anstenitic stainless steel shim positioned between the Low carbon steel and high hardenability Cr-Mo-Mn-Ni P/M material were included to asses the influence of filler metal additions. Joint offset was also reviewed to determine weld integrity relative to the beam position for butt joint combinations. The focus point was manipulated to favor either the P/M material or the adjoining low carbon steel.

RF~ULTS

Metallographic sections were used to evaluate weld metal soundness and overall joint integrity. This provided the opportunity to metallurgically correlate visual observations with given conditions to make reasonable assumptions regarding weldability.

The initial weld samples reviewed were bead-on-plate joints. Most BOP weldments exhibited porosity, solidification cracking and weld sputtering that resulted in significant undercuts, Figure 1. The lower

Figure I - BOP joint on FN-0205 grade at 7.1 g/cm^3 density with laser power of 5 kW and 3.7 m/min travel. Carbon (0.3%) material showed marginal improvement over the FN-0205 grade but neither weld would be considered acceptable. Reducing laser power to 3 kW and travel to 2.2 m/min resulted in somewhat less porosity and cracking because of reduced heat energy input and slower travel speed, which allowed the weld, gases greater time to evolve from the molten puddle before it began to solidify.

In comparison, the bead-on-plate weld shown in Figure 2 indicates a marked improvement with FN-0400 material, high temperature sintered to 7.3 g/cm^3 density. This suggests density along with enhanced particle bonding plays a more significant role than alloy composition, particularly as it relates to nickel additions. As noted previously, lower weld settings of 3 kW @ 2.2 m/min were also beneficial. Weld parameters could likely be further optimized to reduce defects. However, complete elimination of anomalies from P/M bead-on-plate welds will be difficult and impractical, as this is not commonly used to join parts.

As discussed, joint preparation is a critically important factor in relation to weld quality. Because laser weldments are generally accomplished without filler metal, fit-up and joint offset become extremely important considerations. Wide gap spacing results in irregular, concave or undercut weld beads. This can be compensated for primarily by increasing the beam focal diameter or with the addition of filler metal. Joint offset is likewise an important consideration for welding P/M materials to wrought steel compositions. This is illustrated in the comparison between Figures 3 & 4.

Relative improvements in weld quality result when the offset between materials is optimized for each material combination. In Figure 4, positioning the focal point more towards the Low carbon wrought steel substantially reduced both porosity and defect severity. Slower travel speed and/or higher P/M part density should help prevent the solidification crack found in the referenced photomicrograph.

In contrast, overlap joints do not provide sufficient exhaust paths and show a tendency to form weld metal defects, Figure 5. However, this initial study made no attempt to optimize conditions or parameters for each respective weldment.

The small rounded pores in the PF-4650 joined to a low carbon steel grade using an overlap weld, Figure 6, and should not significantly affect joint strength. Dilution with the low carbon overlay material compensated for the high hardenability P/F composition and prevented solidification or stress cracks in the weld metal. Applications incorporating similar materials should not require filler metal to achieve successful weldments. However, if higher alloy grades are required for the overlay material, consideration must be given to the maximum carbon or alloy contents that will provide satisfactory joint integrity.

The high hardenability Cr-Mo-Mn-Ni P/M material butt welded to the 1008 steel also exhibited similar dilution levels with minor incidence of solidification cracks ranging 0,025 mm to 0.15 mm in length along with limited porosity at the weld metal - 1008 steel interface, Figure 7.

The addition of an austenitic filler metal shim, placed between the steel and higher alloy *P/M* grade, Figure 8, eliminated the porosity hut marginally increased the frequency and size of solidification cracks, primarily in *the filler metal.*

The relatively low number and severity of defects found in butt welds of the Cr-Mo-Mn-Ni P/M grade provides promising results. Efforts to determine the optimum combination of weld parameters, e.g. increase focal diameter of the beam, position the focal point above the workpiece, reduce travel speed and/or overall depth of penetration, should result in successful weldments without the need for filler metal additions.

CONCLUSION

This investigation determined that P/M materials require special consideration and should not be laser welded using *standard* wrought steel parameters. Factor influential to the weldment quality and integrity include joint design, material combinations, weld *parameters* and part density. Alloy and carbon content appear to play a less significant role when welding *P/M than wrought steel counterparts.*

Review of the microstructures and related weld conditions provides the following guidelines.

1. Lower laser power levels and slower travel speeds appear to facilitate P/M weldability.

2. Greater weld penetration does not necessarily increase P/M weld strength. The joint strength should approximate the same strength level established by the base P/M grade, yet maintain good weld soundness.

3. Porosity in P/M grades somewhat compensates for faster cooling rates associated with the laser process by lessening the hardenability of higher alloy compositions. However, higher part densities reduce weld defects and have a favorable influence on the laser welding process.

4. Increasing the focal length or beam diameter along with manipulating the beam in relation to the weld helps prevent porosity.

5. If material combinations can be selected to provide appropriate weld toughness and prevent cracking, filler metal may not always be required.

6. Joint designs should incorporate channels or exhaust paths to help remove gases from the weld metal.

7. P/M part designs are conducive to producing economical self-fixturing or aligning joints to meet exacting fit-up requirements without extensive machining. This overcomes a limitation associated with laser welding wrought steel components.

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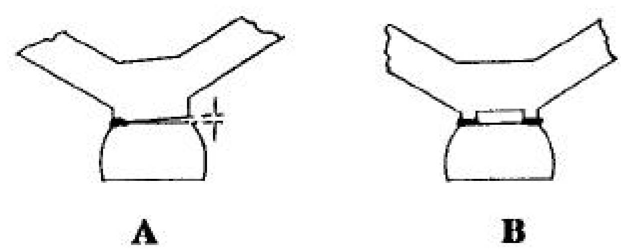

Figure 1 - Schematic of two joint designs for laser welding high hardenability materials.

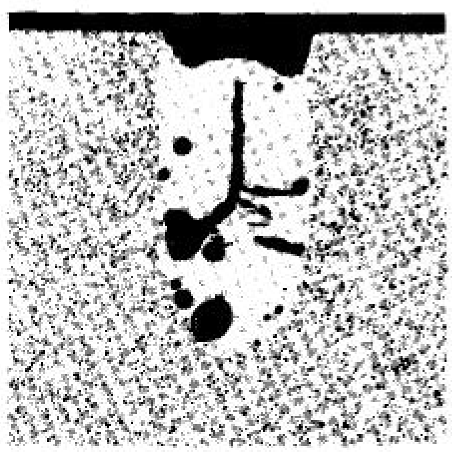

Figure 1 - BOP joint on FN-0205 grade at 7.1 g/cm^3 density with laser power of 5 kW and 3.7 m/min travel.

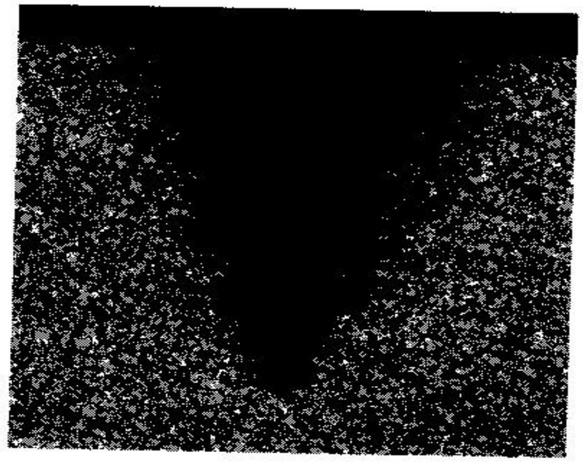

Figure 2 - FN-0400 at 7.3 g/cm³ with laser settings of 3 kW@ 2.2 m/min.

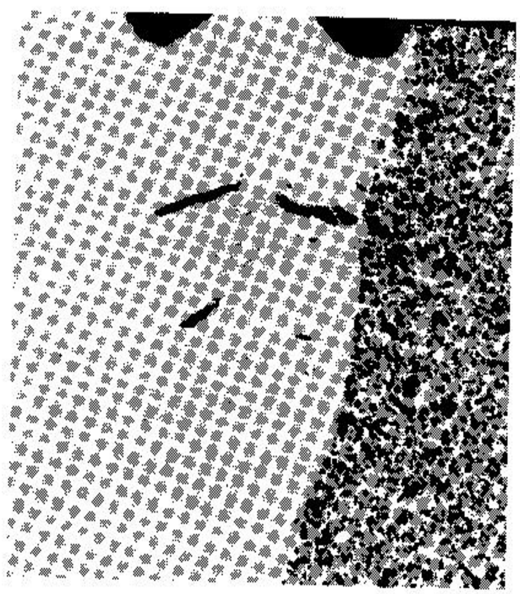

Figure 3 - Butt joint between 1008 wrought steel and F-0005 at 6.8 g/cm³ density, welded using 3 kW @ 2.2 mm/min with focal point offset towards P/M material.

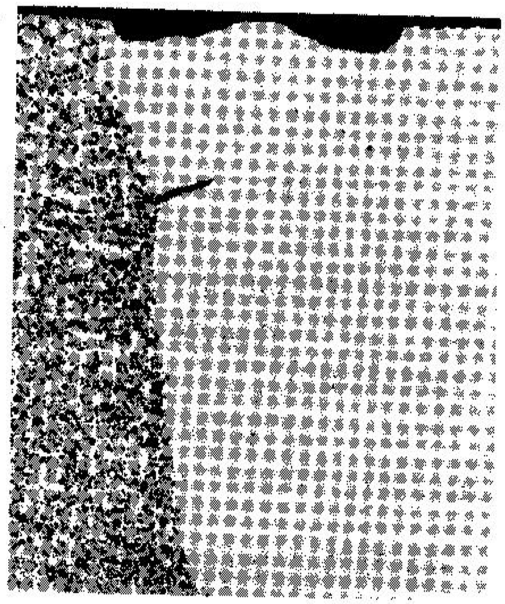

Figure 4 - Same materials and conditions as Fig 3, but focal point was re-directed towards wrought steel grade.

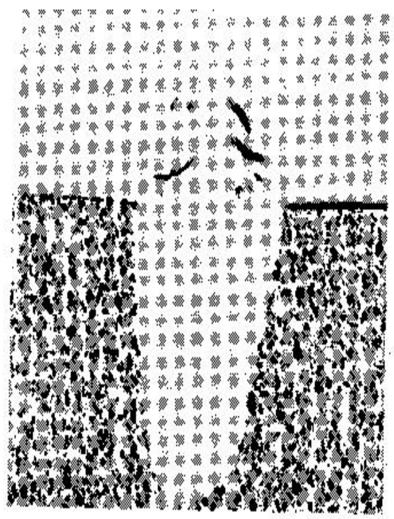

Figure 5 - Overlap weld joining 1008 steel with FN-0205 at 7.0 g/cm³ density using 3 kW @ 2.2 m/min.

Figure 6 - PF-4650 part joined to low carbon steel at weld settings of 4 kW @ 1.3 m/min with 5mm penetration.

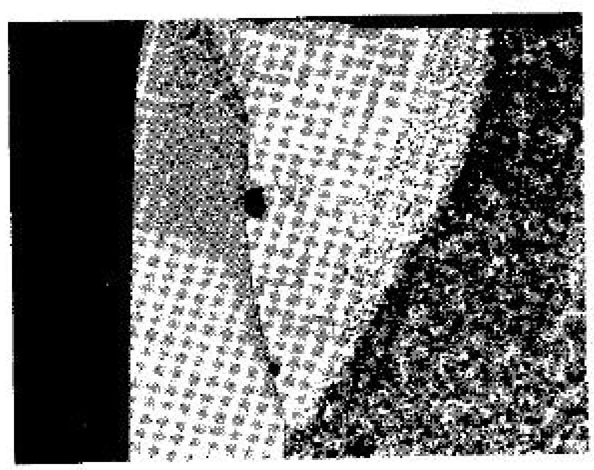

Figure 7 - P/M Cr-Mo-Mn-Ni alloy grade butt welded to low carbon steel. Low carbon steel and weld metal show carbon diffusion from the P/M material. The light etching heat affected zone (HAZ) is martensitic, whereas the base Cr-Mo-Mn-Ni alloy is mainly pearlitic. Weld parameters were 3 kW @ 1.9 m/min.

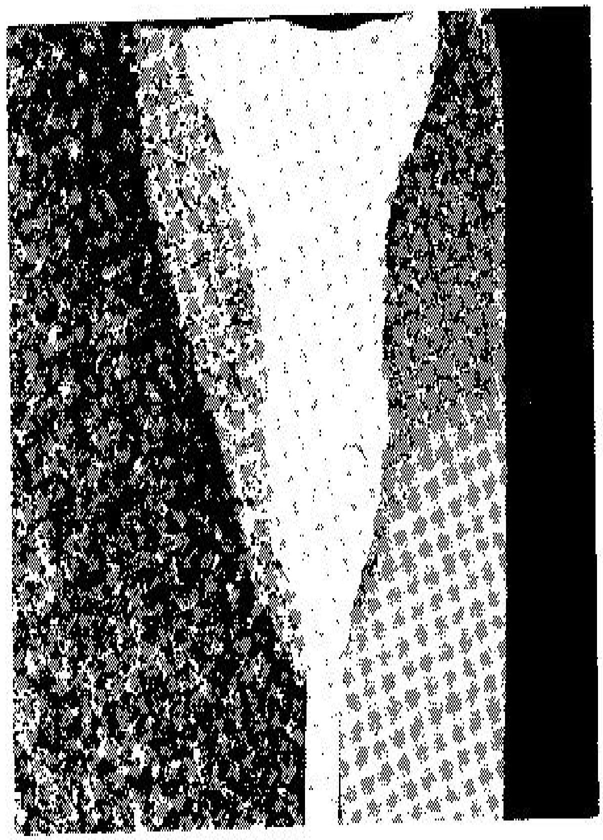

Figure 8 - Same as Fig. 7 with the addition of stainless shim used as filler. Weld metal remains austenitic and shows a 0.3 mm crack.