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A Study on Single Mode Laser Based Plastic-Metal Joining Process

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Abstract: Especially in the automotive industry, the use of plastic and metal joints is preferred for weight savings. Generally, a method called "over molding" is used, where the joint strength is obtained with the plastic material that completely surrounds the metal parts, because plastic and metal cannot be bonded or welded together due to their chemical and physical differences. Today, it is used in the bonding process of joining plastics and metals, but the connection is weak. In order to overcome these problems, a promising approach has been explored by researchers in recent years. In this approach, a two-stage process is used. In the first processing step, laser radiation is applied to form microstructures on the surface of the metallic bonding partner. In the next step, the plastic is mechanically locked to the microstructures with the plastic injection method. A fast beam movement is realized by a galvometric scanning system, which allows scanning variable patterns on the metal surface. Because the process is based on a combination of sublimation and melting, the processing time is much shorter compared to conventional structuring processes. However, this study was done in slow cycles away from mass production in the laboratory setup. In this study, metal-plastic hybrid bonding experiments were carried out in 2 stages consisting of laser micro treatment of the metal surface and plastic injection process. After the injection process, the plastic is mechanically locked onto the processed surfaces.

Keywords: Laser assisted metal and plastic joining, Light weight, Plastic-metal joining.

Introduction

Usage of plastic and metal connections has a great potential in the automotive industry in order to produce light weight vehicle body (Heckert & Zaeh,2014). A method called "overmolding" is generally used to join plastic and metals. the strength of the plastic part is improved by completely surrounding the metal. The aim of overmolding is to combine multiple plastic parts together in a seamless fashion to create a durable and uniform product (Paul et al., 2012). Plastic and metal can only be partially combined to each other due to their chemical and physical differences.

The bonding process or mechanical connection are also used in the joining of plastics and metals (Bergmann & Zaeh,2014). These connections usually require additional processes. Cost-up and increased process time issues are the main disadvantages of aformentioned processes. To overcome these problems, a promising approach has been developed by researchers in recent years. LAMP (Laser assisted Metal and Plastic Joining) method is preffered to join metal and plastics (Roesnera et al.,2011). On the other hand, it is foreseen that this method can

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be used in direct joining of aluminum alloys and steel materials. Bimetallic corrosion, also called galvanic corrosion, occurs between aluminum and steel connections. Bimetallic corrosion can be prevented by combining the plastic component by sandwiching between different metal sheets with the LAMP method without additional parts or tools such as adhesives and rivets. In addition, this type of coupling provides design flexibility (Katayama & Kubata, 2007). This approach uses a two-step process. In the first processing step, the laser beam is used to create microstructures on the metal surface. In the second step, the plastic material is injected onto the metal with the plastic injection method and the plastic is mechanically locked into the microstructures. In addition to mechanical locking, a chemical bond is formed with the help of atomic diffusion (Katayama & Kubata, 2007; Roesnera et al.,2011).

In this study, method development studies were performed using LAMP in accordance with mass production speeds, starting from the laboratory level. Hybrid structures were obtained that can meet customer needs in automotive industry. Characterization and optimization of the connections were performed. A rapid beam movement was achieved with a galvometric scanning system that allows scanning of variable patterns on the metal surface. The surface treatment time was shortened. Mass production compared to traditional structuring processes.

Method

ST52 steel in 1.8 mm thickness and P6-6 GF30 plastic in 3 mm were used in this study. Hybrid joining process were performed by Ytterbium fiber laser. The laser is in Continuous Wave (CW) mode at 1070 nm wavelength. Laser beam profile is Gaussian with 1 cm diameter and it is in TEM_{00} mode. Single mode laser was used in the study. The hybrid joining process consists of 2 steps as shown in figure 1. Channels were processed on the metal surface at 400 micron intervals with the help of the experimental setup shown in Figure 2. Micro channel surface texturing studies were carried out with 7 different parameters are illustrated in Table 1.

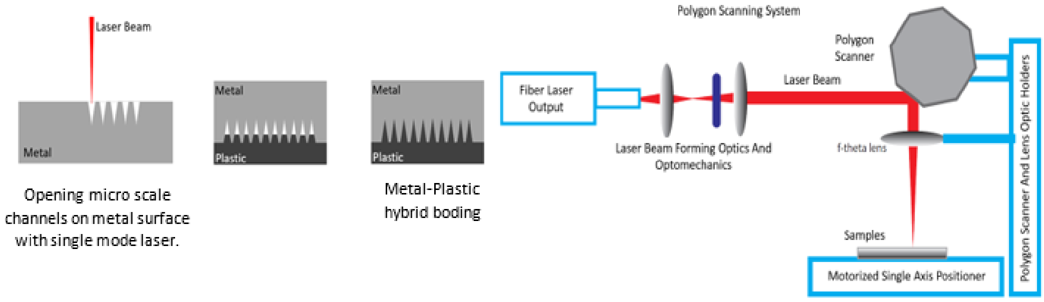

Figure 1. Hybrid joining process steps and experimental setup of polygon scaning system.

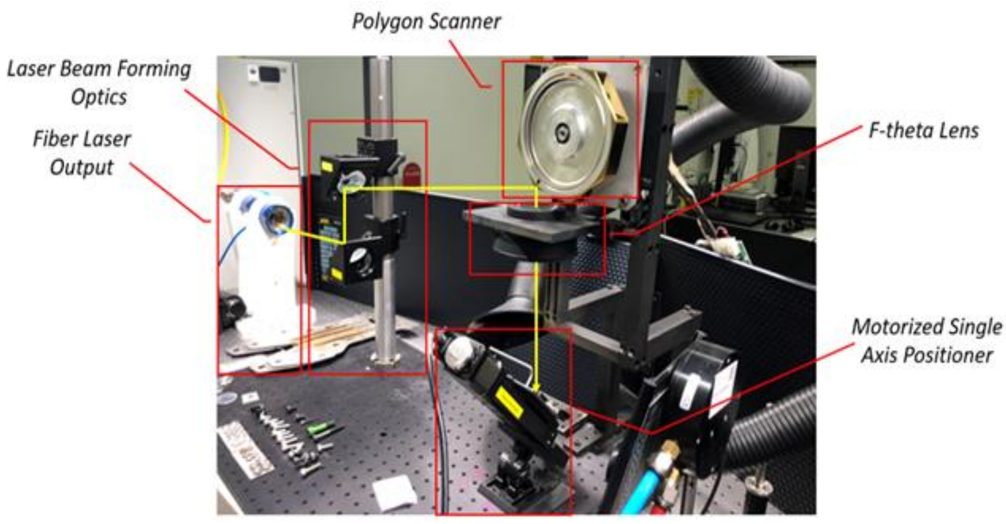

Figure 2. Laser assisted surface texturing experimental setup. In the experimental setup, the yellow arrow simulates the laser beam.

Table 1. Laser parameter matrix of laser surface structuring process.

Specimen Number	Lazer Power (W)	Polygon Speed (RPM)	Time (s)	Channel Angle (°)
S1	1500	3000	2	90
S2	2000	3000	1	90
S3	2000	3000	1,5	90
S4	2500	3000	1	90
S5	2500	3000	1,5	90
S6	2500	3000	3	90
S7	2000	3000	1,5	45

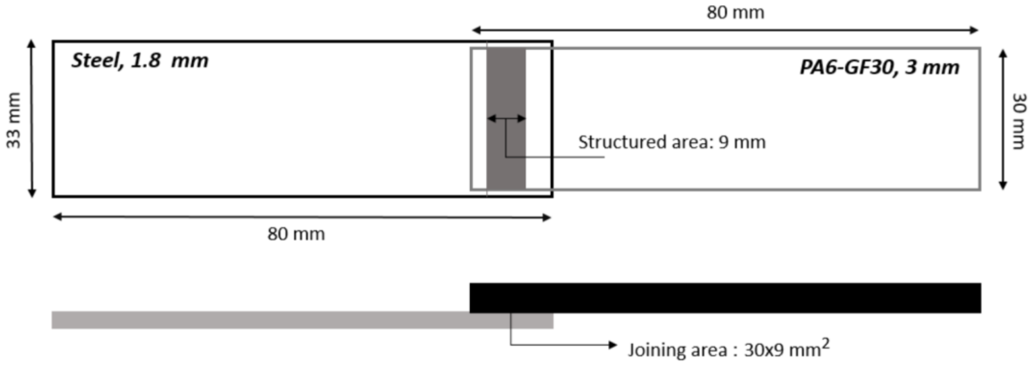

Figure 3. Tensile test specimens dimensions after plastic injection.

Tensile tests were performed at 50 kN capacity SHIMADZU equipment with 5 mm/min tensile speed rate at room temperature. The geometry of tensile test specimens after plastic injection was illustrated in Figure 3. Specimens were cut out by METKON METACUT 302 metallographic sensitive cutting equipment, and then were mold by METKON ECOPRESS 52 hot molding machine. The standard metallographic grinding and polishing were performed by METKON FORCIPOL 202 unit. Macro structural investigations were performed by Nikon SMZ745T optical microscope.

Results and Discussion

The width and depth ratios of the obtained non-angle channels were measured by optical microscope. Angled channels as well as the tensile specimens were selected considering the most appropriate depth, width ratios and channel geometries.

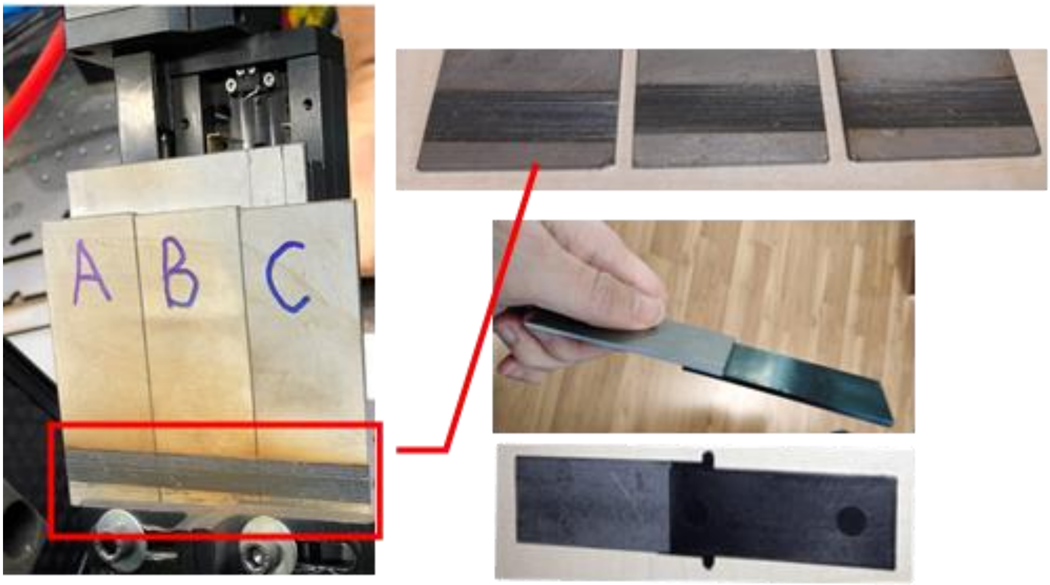

Figure 4. Surface-treated samples with channel structures and tensile test specimens (S6) and dimensions after plastic injection.

The channel geometries were determined by optical microscope using the laser parameters illustrated in Table 1. The channel depth increased with increasing laser power and/or processing time. Figure 4 shows the surface-treated specimens by laser with channel structures. Tensile test specimen geometry after plastic injection on S6 specimen was also depicted in Fig 4.

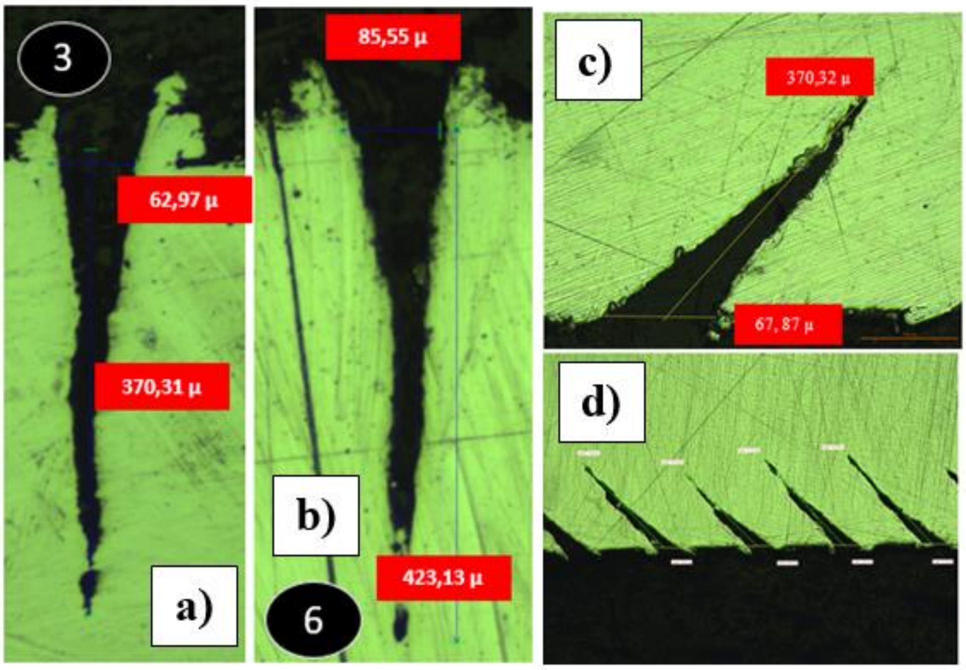

Figure 5. Macro images of metal specimens with surface textured at 0° and 45° angle; a) S3, b) S6, c) S7 and d) Cross section of S7.

Fig. 5 shows the macro section images of metal shet specimens with surface textured at 90° and 45° angle. The effect of laser power and process time on the channel geometry was also illustrated in Fig 5. It has been determined that the length and the width of the channel were increased, so the aspect ratio value was decreased.

The channel widths and depths formed on the sheet surfaces of the laser-textured samples are given in Table 2. Comparison of S1 and S2 shows that the aspect ratio increased with the increase in laser power. It has been determined that increasing the laser power in S4, S5 and S6 causes an increase in aspect ratio of S2 and S3. The aspect ratio and width-depth results of S3 and S6 showes that the channel depth increased with the increase in laser power and processing time, whereas the aspect ratio decreased as a result of the increase in channel width.

Table 2. Channel dimensions results after laser surface structuring process.

Specimen Number	Channel Edge Width (µm)	Channel Depth (µm)	Acpect Ratio (Depth/ Width)	Channel Angle (°)
S1	58,22	222,32	3,81	90
S2	55,84	276,94	4,95	90
S3	62,97	370,31	5,88	90
S4	48,71	286,45	5,88	90
S5	64,16	354,2	5,52	90
S6	85,55	423,13	4,94	90
S7	67,87	370,32	5,45	45

Tensile strength of S3, S6 and S7 specimens were obtained as ~12 MPa/mm^2, ~13 MPa/mm^2 and ~15 MPa/mm^2, respectively. It was concluded that the channel structures formed at an angle of 45 degrees to the surface in S7 with the S3 parameters increased the mechanical locking between metal and plastic. In Figure 6, the images of the broken parts of the S7 after the tensile test are shared. Fracture after tensile test in S3, S6 and S7 occurred by separating the plastic material from the channels as in Fig. 6

Figure 6. Image of broken parts from S7 specimen after tensile test.

Conclusions

The motivation point of the laser-assisted joining technique was chosen in the study. It is to develop an alternative joining technique that provides solutions to the problems of chemical compatibility, adhesion, bonding of dissimilar materials, curing problems of adhesives, extra surface applications required for adhesives, extended cycle times, and homogenization problems. The surfaces of metals formed with the laser method used in the study were functional and a part metal-plastic hybrid form was created with the back injection method to be used in plastic injection. The test results are summarized as follows:

- The relationship between the ratio of channel depth to mouth width and tensile test results play an important role to determine the optimum surface texture parameter.
- The joint strength of the S3 specimen with 90° channel geometry was obtained as 12.5 MPa/mm^2.
- The joint strength of the S6 specimen was obtained as 13.4 MPa/mm^2
- The joint strength of the S7 surface textured specimen with an angle of 45° was obtained as 15,6 MPa/mm^2
- The textured surface with a 45° angled channel structure has increased the bond strength between plastic and metal.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

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