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Innovation of laser direct joining between metal and plastic†

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1. Introduction

Many materials including metals, plastics and ceramics have been widely used in many industrial applications such as automobiles, aircrafts and electronic devices. Joining of these dissimilar materials is necessary and important from a manufacturing viewpoint. The features of metals include high strength, high toughness, high heat conductivity and high heat resistance. Plastics are characterized by lightweight, high corrosion resistance and excellent formability. Polyethylene terephthalate (PET) is known as a typical engineering plastic and commercially available bottles. On the other hand, ceramics are used owing to their high hardness and/or good heat resistance. Silicon nitride ceramics (Si_3N_4), a chemical compound of silicon and nitrogen, is utilized as a bearing for engines or a rotor blade of turbine.

The dissimilar joining is generally performed using adhesive bonds (glues) or mechanical fastering such as bolts and rivets. However, these joining processes have some problems in terms of environmental restriction of volatile organic compound (VOC) emission and mass production. Therefore, the authors have developed a new laser direct joining method between metals and plastics which is named Laser Assisted Metal and Plastic joining method (LAMP joining method) [1].

The LAMP joints between engineering plastic PET and stainless steel SUS304 before and after the tensile shear test are shown in **Fig. 1**. The top surface of PET was not damaged to be as smooth as what it had been before the laser irradiation. However, many bubbles of sub-millimeter sizes were formed inside the plastic near the joint. The shear load of the joint was about 3000 N, and the base PET was elongated sufficiently as shown in the lower photo of Fig. 1. Such strong joints were produced by the laser direct joining process with many small bubbles.

The LAMP joints were examined with transmission electron microscopes (TEM), and these examples are shown in **Fig. 2**. The TEM image demonstrates that the metal and the plastic are tightly bonded on the atomic or molecular sized level. The base metal and the intermediate layer were identified to be fcc gamma (γ) phase and 5 nm-thick Cr-oxide film from these diffraction patterns, respectively. It was therefore revealed that a strong joint could be produced by atomic, nanostructural or molecular bonding of the metal and the plastic through the oxide film on the metal plate surface. Not only the anchor (mechanical bonding) effect but also Van der Waals interaction force and chemical bonding were considered as bonding mechanisms of LAMP joining.

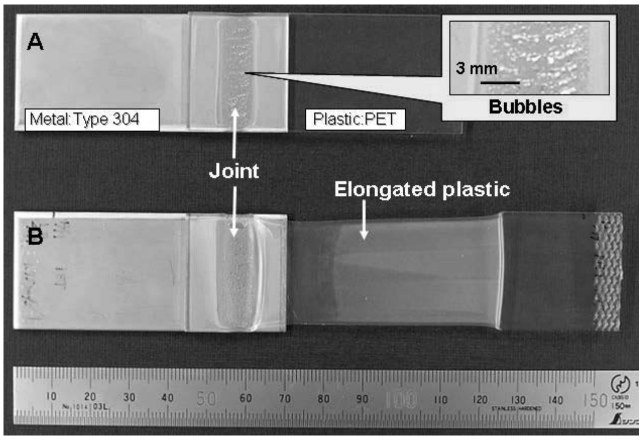

Fig 1 LAMP joints before and after tensile shear test.

In this research, LAMP joining method with a 3-kW diode laser (LD) was applied to join of Si_3N_4 ceramic and PET engineering plastic. The LAMP joining between the ceramic and the plastic was carried out to optimize welding speed. The obtained joints were evaluated by the tensile shear test. Furthermore, the joints were observed in details through TEM in order to investigate the joining structure.

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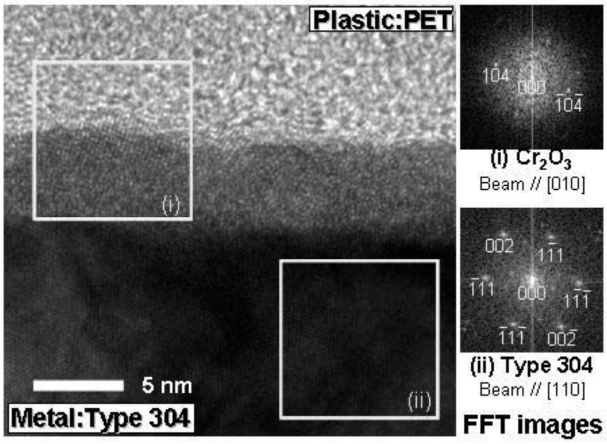

Fig. 2 TEM image and FFT analyses of LAMP joints.

2. Materials and Experimental Procedures

The ceramic used was silicon nitride plates. The size is 110 mm x 30 mm with 3 mm thickness. The plastic used was PET plates. The size is 70 mm x 30 mm with 2 mm thickness. The transmissivity of amorphous PET is high owing to its transparency. PET is decomposed at more than 600 K. On the other hand, Si_3N_4 has much higher temperature of decomposition than PET.

This study was performed with the objective of producing a strong LAMP joints of Si_3N_4 ceramic and PET engineering plastic. The LAMP joining with a LD beam was carried out in the air without shielding gas for cooling the plastic and keeping the clean surface conditions as illustrated in **Fig. 3**. The LD beam is in the line shape whose major axis is 23 mm. The focused position of the LD beam is on the metal surface. Laser power is 500 W and traveling speed is 4 mm/s to 8 mm/s. To evaluate the mechanical properties of LAMP joints, SHIMAZU AG-10kNE was used as a tensile shear tester.

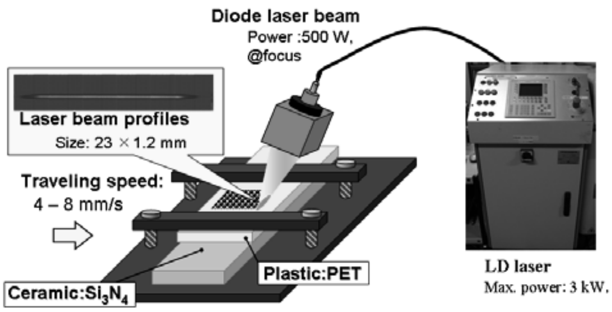

Fig. 3 Schematic experimental set-up of LAMP joining.

3. Experimental Results and Discussion

A silicon nitride Si_3N_4 plate and a PET plate were overlapped, and then the LD beam was irradiated from the plastic side. The welding speed was changed from 4 mm/s to 8 mm/s at the laser power of 500 W. The typical joining result at 6 mm/s speed is shown in **Fig. 4**. The top surface of PET was not damaged and as smooth as it had been before the laser irradiation as well as the previous works of LAMP joining [1, 2]. Therefore, LAMP joints of Si_3N_4 ceramic and PET engineering plastic were successfully produced. It was found that many bubbles were formed inside the plastic near the LAMP joints.

The tensile shear strengths of the LAMP joints were measured. The shear loads had the peak at about 6 mm/s, and over 3100 N was achieved. Furthermore, the LAMP joint made at 6 mm/s was observed with TEM. The observation image is shown in **Fig. 5**. The bright upper

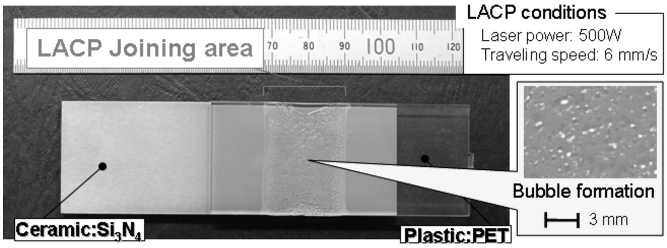

Fig. 4 Surface appearance of LAMP joint of Si_3N_4 and PET produced at 500 W and 6 mm/s, showing bubbles.

part is PET polymer and the dark lower area is Si_3N_4. The TEM image demonstrates that the ceramic and the plastic are tightly bonded on the atomic or molecular size level. Moreover, it was found that the PET polymer

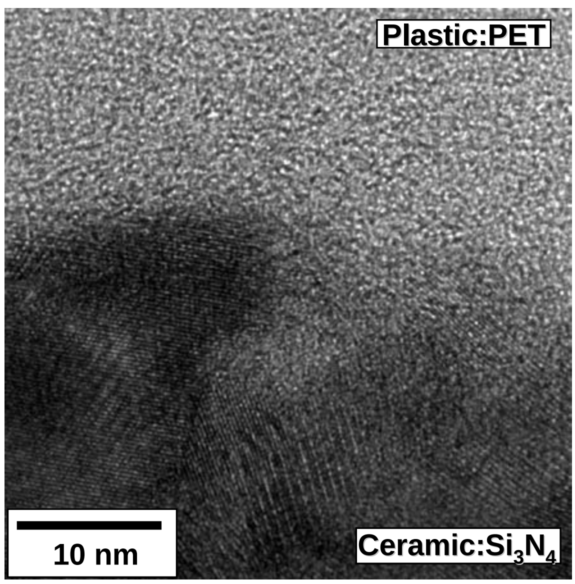

Fig. 5 TEM image of obtained LAMP joints of Si_3N_4 and PET.

entered the nanoscale hollow formed on the surface of Si_3N_4. It was therefore considered that the strong joint could be produced by atomic, nanostructural or molecular bonding of the metal and the plastic on the ceramic plate surface, where not only the anchor (mechanical bonding) effect but also Van der Waals interaction force and chemical bonding were considered as joining or bonding mechanisms.

4. Conclusions

We have successfully produced new LAMP (Laser-Assisted Ceramic and Plastic) joints between the commercially available ceramic Si_3N_4 and the engineering plastic PET. The joint possessed over 3100 N shear load strength in 30-mm-width plastic samples of 2 mm in thickness. The base plastic was elongated because of the formation of strong joints. Moreover, the TEM image of the LACP joint demonstrates that the ceramic and the plastic are tightly bonded on the atomic or molecular size level.

Acknowledgments

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