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Prevention of porosity in steel/Al laser welded joint with cold-sprayed steel interlayer by means of beam oscillation

Kyohei Maeda[a,b,*], Yuji Sato[c], Keisuke takenaka[c], Yoshiaki Kurita[a], Tesuo Suga[c], Masahiro Tsukamoto[c]

[a] *Graduate school of engineering, Osaka University, 2-1 Yamadaoka, Suita, Osaka, Japan.*
[b] *Kobe Steel, Ltd., 100-1 Miyamae, Fujisawa Kanagawa, Japan.*
[c] *Joining and Welding Research Institute, Osaka University, 11-1 Mihogaoka, Ibaraki, Osaka, Japan.*

Abstract

Nowadays, in the automotive industry, multi-material body designs are widespread for weight reduction. It is well known that in this type of bodies, dissimilar metal joining is one of the main problems. For this reason, we have developed a dissimilar joining method with a cold-sprayed steel interlayer. In this procedure, a steel coating was sprayed onto an aluminium surface, and then, was laser welded to a steel sheet. In our previous research, it was found that porosity in the weld metal occurred in this process probably due to gases in the coating. It has been reported that oscillation welding is effective in preventing porosity in the weld metal of aluminium laser welds. In this study, therefore, the influence of beam oscillation on preventing the porosity formation in the laser welds with the coating was investigated.

Keywords: Laser welding; Cold-spray process; Dissimilar joining; Beam oscillation; Porosity

1. Introduction

Recently, carbon neutrality has become a major goal in order to prevent Climate Change and therefore, the reduction of CO_2 release is now serious problem in the automotive industry. Weight-saving of vehicle bodies is effective in Improving fuel efficiency, resulting in a decrease of this type of gas. Nowadays, multi-material body structures, using lightweight materials such as aluminium and plastic together with steel, are commonly used. It is generally accepted that dissimilar joining is a major challenge when manufacturing such cars as it is very difficult to weld various kinds of non-ferrous metals to steel. For instance, brittle intermetallic compound (IMC) layers such as $FeAl_3$ and Fe_2Al_5 form at the interface between the steel and the aluminium[1)], or possibly, cracks in a fusion-zone or the IMC layers occur[2)] when these two metals come under high-temperature above 673 K[3)]. For this reason, currently, fasteners such as bolts, rivets and screws are often used for connecting dissimilar materials, though most of these methods need longer time to join materials than welding[4], leading to higher production costs.

Laser welding is a quick and single-sided joining process, used widely in various kinds of industries such as automobiles, railways and aerospace. This type of welding is thought to be one of the best ways for dissimilar joining in terms of cost, though the aforementioned problem concerning welding defects must be solved.

In order to avoid this drawback, we have developed a dissimilar laser joining method, using a cold-sprayed coating as an interlayer[5]. In this process, a steel sheet is welded to the steel coating, formed onto an aluminium surface, as shown in Fig. 1. It was found that laser welds with such a coating was stronger than those without it, though a great deal of porosity was generated in the weld metal, where the fracture in tensile testing occurred. So as to improve the joint strength, this type of failure needed to be avoided by preventing the porosity. It is recognised already that porosity forms when bubbles, containing gases, are trapped by the solidification interface[6]. In our previous research, it was discovered that the amount of porosity decreased drastically as a laser scanning speed became slower[7], which make a weld bead wider and hence, the solidification rate of the molten pool became lower, leading to helping the bubbles go outside. However, such a slower speed is not desirable in terms of production costs.

Therefore, this research aims to establish a laser welding process for preventing porosity formation with a higher scanning speed. It has been reported that the application of beam oscillation is able to enlarge the molten pool and both in aluminium and magnesium welding, the oscillation is effective in reducing the amount of the porosity[8-10]. In this study, the influence of beam oscillation on preventing porosity in laser welding of steel to aluminium with a cold-sprayed coating was investigated.

2. Experimental procedure

3.0 mm-thick AA7204 was used as a substrate of a cold-spray process. Water-atomised steel powder, listed in Table 1, with an average diameter of 43 μm was sprayed onto an aluminium surface by a high-pressure and high-temperature cold-spray system (Plasma Giken Co., PCS-100) at a pressure of 5 MPa and temperature of 1273 K, and a 2 mm-thick steel coating was formed. A 1.4 mm-thick hot-stamping steel with tensile strength of 1.5 GPa was lap-welded to the sprayed sample by a disk laser (TRUMPF, TruDisk-16002) with the spot size of 440 mm in diameter (D4s). The experimental set-up is illustrated in Fig. 2. Beam oscillation was carried out by a galvanometer scanner (TRUMPF, PFO) in combination with a linear actuator, moving at a speed of 60 mm/s. The laser was scanned circularly, as shown in Fig. 3, with a diameter of 0.6 mm, at a laser power of

Fig. 1. Schematic illustration of laser lap-joining of steel to aluminium with a cold-sprayed steel interlayer

Table 1. Chemical compositions of steel powder (wt%)

C	Si	Mn	P	S	Fe
0.004	0.01	0.14	0.004	0.010	Bal.

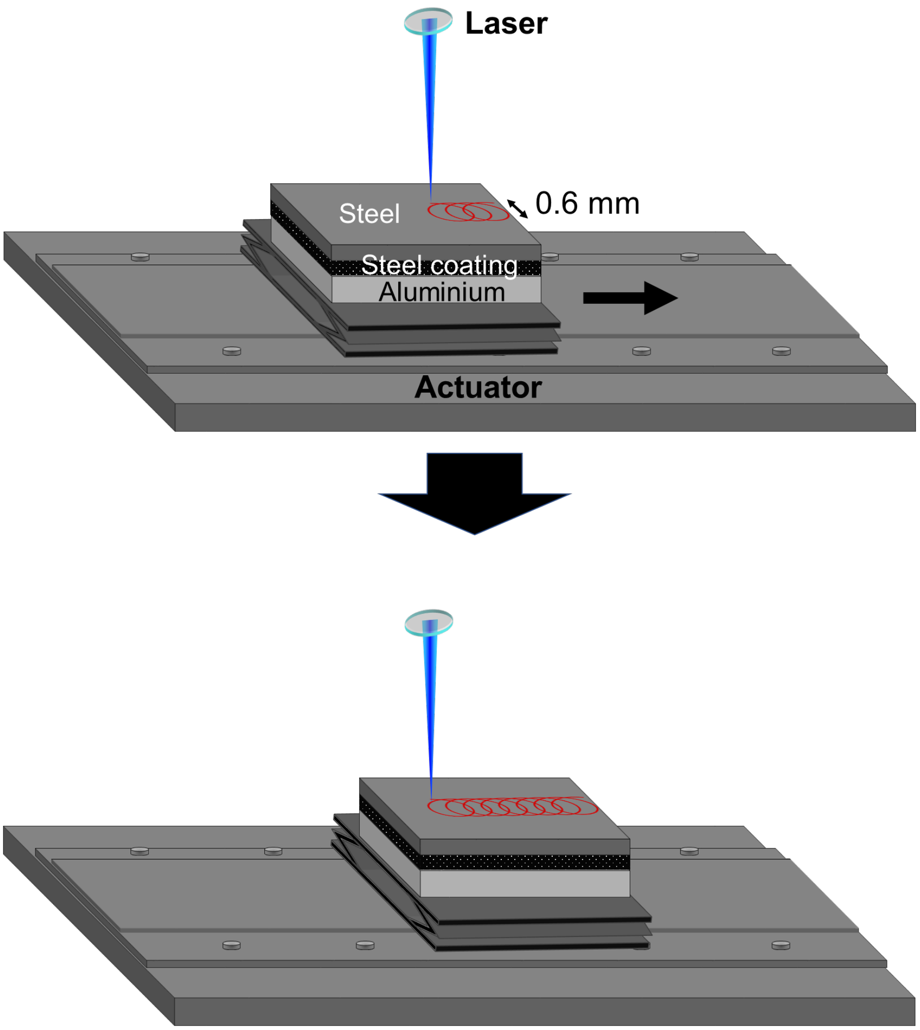


Fig. 2. Schematic illustration of welding set-up

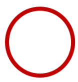
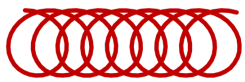
	Shape of laser scanning by PFO	Laser irradiation area on specimens moved by actuator
Without oscillation		
With oscillation		

Fig. 3. Schematic illustration of laser scanning pattern

2500W and oscillation frequencies, which means number of circular scanning per second, of 200 and 400 Hz. Welding without the oscillation was also compared. The cross-section of the welds was imaged by an optical microscope. Porosity percentage in the weld metal F_p, as calculated by equation (1), and bead width at the interface between the steel and the coating D_w were quantified using an open-source software Image J.

$$F_p = 100\ (A_p / A_w) \tag{1}$$

where A_p is the area of the porosity and A_w is the area of the weld metal.

3. Results and discussion

The cross-section images are shown in Fig. 4. The oscillation welding at a frequency of 200 Hz was most effective in decreasing the amount of porosity, which was approximately 87% less than that without oscillation, while it increased at 400 Hz. It was also found that the weld bead at 200 Hz was wider than those in other conditions, suggesting that the former's solidification rate was lower than the latter's rates and hence, gases were able to be released from the molten pool to outside.

The results have shown that the beam oscillation was very effective in reducing the amount of porosity in the weld metal. The oscillation frequency of 200 Hz was the best in this study.

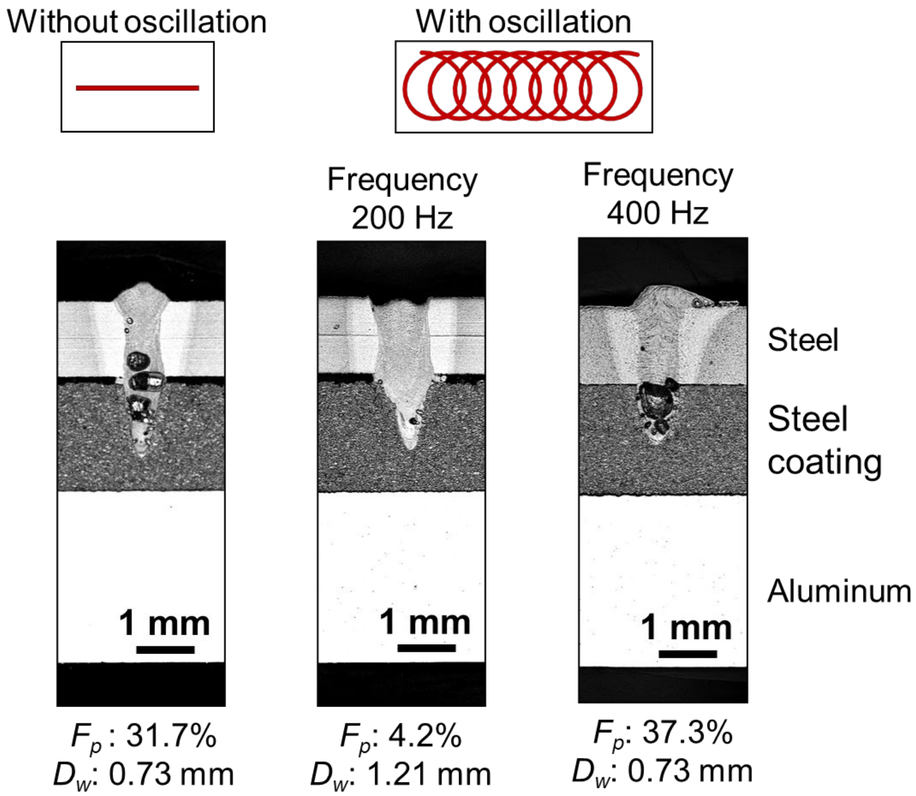


Fig. 4. Transverse cross-section images of laser welds

4. Conclusion

This study investigated the influence of beam oscillation on preventing porosity in laser lap-joining of steel to aluminium with a cold-sprayed steel interlayer. The oscillation welding at the frequency of 200 Hz was most effective in decreasing the amount of the porosity, which was approximately 87% less than that without the oscillation.

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