New Materials Need the Help of New Joining Technology†

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Abstract

The approach to solving the problems in joining and welding of the new functional materials and difficult-to-weld conventional materials has been reviewed in relation to good matching with new joining and welding processes with the capability of making a continuous welded joint.

KEY WORDS: (Electron Beam Welding), (Laser Welding), (A-TIG), (Braze Welding), (Laser/Arc Hybrid Welding), (Friction Stir Welding)

1. Introduction

Developments of new functional materials give us a good chance to create superior industrial products offering a strong competition in the market, where they can be actually used as the components of the products. For this purpose, joining and welding processes applicable to new functional materials are necessary for constructing the products using new materials. However, it is not easy in many cases with conventional welding processes.

Even in conventional materials, which are widely used, some are not easy to weld and involve high costs to ensure the quality of the welds.

Thus, new high efficiency welding processes applicable to new materials and conventional materials, which are difficult to weld, are required as one of the methods for surviving the competition in the production industry.

On the other hand, some new joining and welding processes have been developed from new concepts, but because of their specialty many of them are difficult to use widely in practical production industries.

Therefore, when a good matching of new joining process with new materials can be achieved, this has a high potential to create new industrial products.

In this paper, the approach to solving the problems in joining and welding the new functional materials and difficult-to-weld conventional materials has been reviewed in association with introducing new joining and welding processes, especially those, capable of making continuous welded joints.

2. New Joining and Welding Processes

Table 1 shows typical new joining and welding processes, focused on the processes, which can make continuous welded joints by arc welding. They can be classified into 3 types, that is, modified types of conventional processes, hybrid types between conventional processes and new processes, and newly developed types from new concepts. These processes are not used widely, but gaining their applications in practical productions, though they are limited.

3. Examples for the Approach to Solving the Problems

Table 2 shows the typical new functional materials, which are expected as structural components together

Table 1 Typical new joining and welding processes for continuous welded joints.

Process type	Processes
Conventional, but special process	■ Electron beam welding
	■ Laser welding
Modified process	■ A-TIG
	■ Braze welding (Arc, Laser)
Hybrid process	■ Laser/Arc hybrid Welding
New concept process	■ Friction stir welding (FSW)

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Table 2 Typical examples of good matching between new functional materials expected as structural materials and new joining and welding processes with continuous welded joints.

Materials		Processes proposed or expected
Conventional materials difficult to be welded	Low sulfur contained stainless steel	A-TIG welding
	Zn-coated steel sheet	Laser/Arc hybrid welding
	Die cast, Thixomolded materials	FSW
	Metal matrix composites	FSW
	Dissimilar metal joining of Al to steel	Braze welding
Newly-developed materials	Porous metal	(No process for direct joining)
	Ultrafine grained metal	Ultra-narrow gap welding Laser welding FSW
	High nitrogen steel	Laser welding (Solid-state process [Friction, Diffusion])
	Amorphous alloy	Electron beam welding Laser welding (Friction, pulsed-current and explosion weldings)

with some conventional materials, which are widely used as structural components, although difficult to weld. Typical examples of applying new joining and welding processes to these materials are reviewed as follows,

3.1 Conventional materials difficult to be welded

3.1.1 Low sulfur-contained stainless steel

To improve the corrosion resistance, sulfur content in stainless steel should be reduced to several tens of ppm. However, this type of low sulfur stainless steel became difficult to weld with enough depth of penetration in GTA welding. A-TIG process [1] is a new welding process, in which activating flux consisting mainly of TiO_2 is supplied to the weld pool by coating it on the weld line prior to GTA welding. This activating flux increases the penetration depth drastically to 1.5 to 2.5 times compared with the depth without flux by changing the fluid flow from outward to inward. Recognition of the mechanism will result in the wide application to a variety of metals [2].

3.1.2 Zn-coated steel

Zinc-coated steel is widely used in automobiles and other industries for the protection from corrosion. However, in welding, pits or blow holes are likely to occur in the weld bead as well as severe spattering due to vaporization of zinc, particularly in lap-joints. Practically, to avoid this, careful selection of welding conditions and joint gap are conducted, but it still remains as a big problem in MAG arc welding, and laser welding too. One possible solution is laser/arc hybrid welding process as shown in Fig. 1 [3]. A laser beam makes a key-hole which enables the release of zinc vapor through it to the open air and assists the stability of the following arc as well as increasing the heat input give enough time for blow holes to escape out from the weld pool surface. Thus, high speed and sound welding became possible even without a gap at the lap-joint [3]. Similar application to primed steels will be expected.

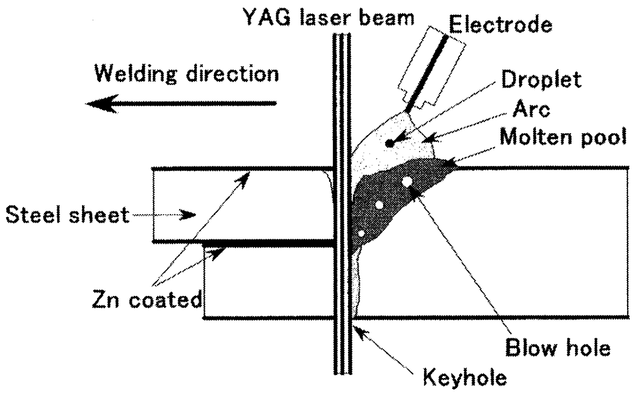

Fig. 1 Schematic illustration of the weld zone of a longitudinal cross section showing the principle of laser/arc hybrid welding process of Zn-coated steel in a lap joint [3].

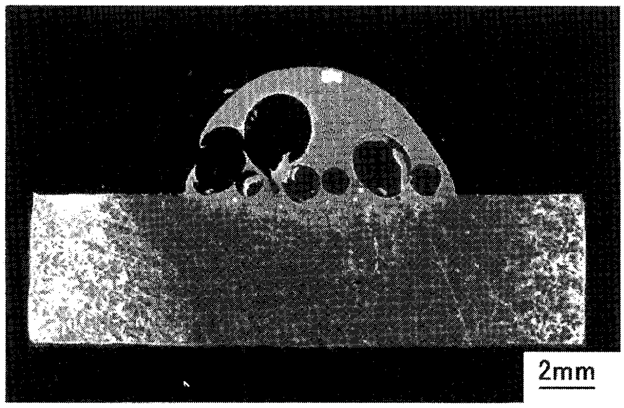

Fig. 2 Blow holes appeared on the cross section of the weld bead of AZ91D Mg alloy die cast welded by MIG arc with AZ61 electrode wire.

3.1.3 Die cast and thixomolded materials

In welding of these materials, blow holes occur inevitably in the weld metal as shown in Fig. 2 due inherently to included gas in the materials during casting [4]. Friction Stir Welding (FSW) [5-6] is quite suitable for joining these materials without blow holes, because FSW is solid-state process. In addition, at the same time during joining, the modification of cast structure is performed by the stirring action of a probe which results in a fine-grained recrystallized structure and the elimination of small cast defects. Figure 3 shows the microstructure of the cross section of a FSW joint of thixomolded AZ91D Mg alloy sheet [7]. Up to now FSW applications are limited to comparably soft metals as Al, Mg and Cu alloys. FSW tool development is the coming target for spreading the applications to a variety of the metals.

3.1.4 Metal matrix composites

Ceramic particulate aluminum metal matrix composite (MMC) is expected as an anti-wear and heat-resistant lightweight material with high conductivity and in addition with a comparably wide variety of shapes. However, welding of MMC is difficult due to blow holes and cavities as well as segregation of ceramic particles and reaction with molten metal in the weld metal as shown in Fig. 4, which shows macrostructure of a YAG laser welded joint of 10%Al_2O_3 particulate 6061 Al alloy matrix composite plate. For this case, FSW is also a suitable joining process as shown in Fig. 5 with the same material as in Fig. 4 [8]. Defect free joints with smooth surfaces can be obtained and Al_2O_3 particles are

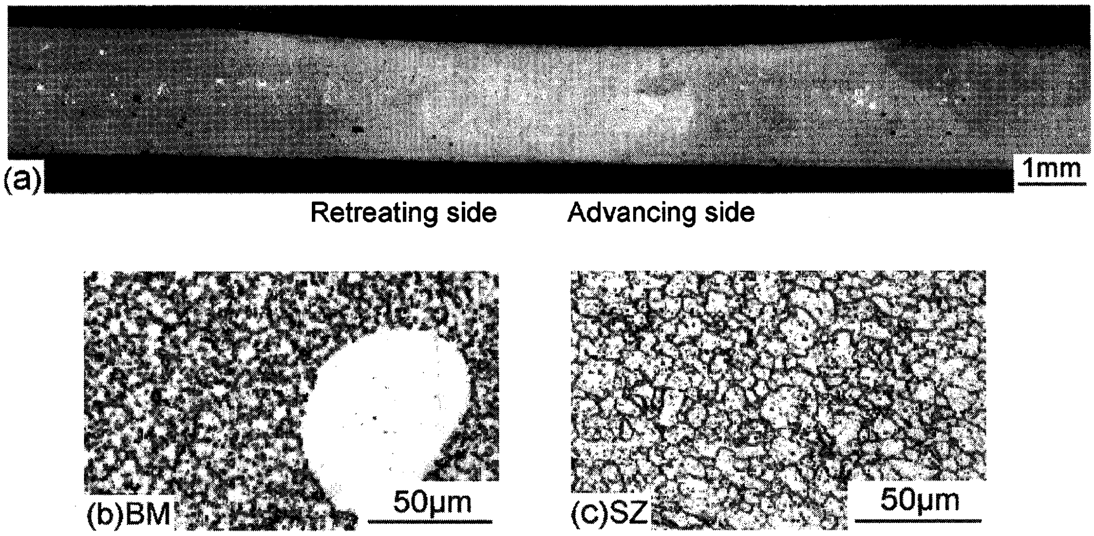

Fig. 3 Microstructure of cross section of FSW joint of thixomolded AZ91D Mg alloy sheet; tool rotation speed 1750rpm, travel speed 50 mm/min [7].

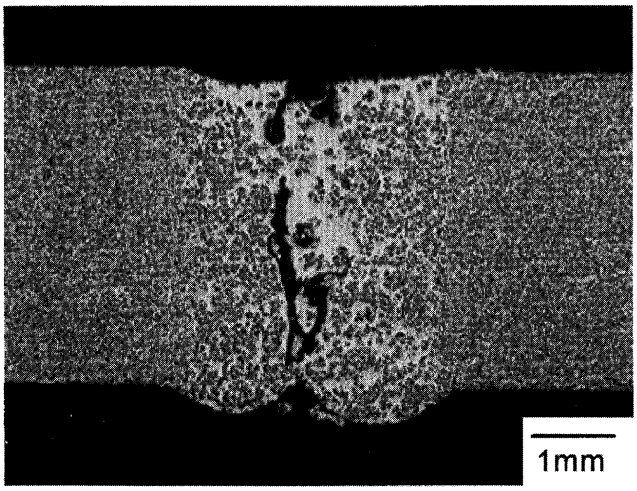

Fig. 4 Macrostructure of cross section of YAG laser welds of 10%Al_2O_3 6061 MMC.

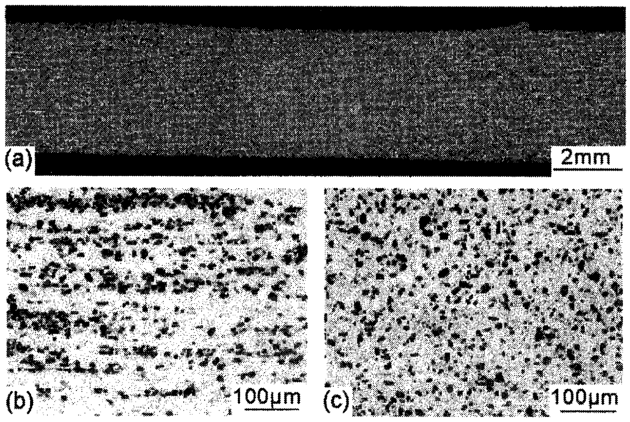

Fig. 5 Macrostructure of cross section of FS welds of 10%Al_2O_3 6061 MMC in (a), and microstructures of base metal (b) and stirred zone (c) [8].

uniformly distributed in the stirred zone. Dissimilar metal joints between MMC to Al alloy plate are also possible for both butt and lap joints. Wear of the FSW probe is a remaining problem to be solved for higher volume fractions of ceramic particles.

3.1.5 Dissimilar metal joining of aluminum to steel

For weight saving, for example in automobiles, dissimilar metal joining technology of aluminum to steel is required [9]. In this joint combination, direct welding is difficult due to the formation of brittle intermetallic compound at the interface.

However, YAG laser welding with precise control of heat input as well as joint shape makes it possible by suppressing the compound layer thickness to less than several micrometers, and results in dissimilar joint showing good joint strength with fracture positions in the HAZ of Al alloy [10]. Another possible process is braze welding, in which steel is not basically melted by using Al-Si low temperature filler metal. Laser and MIG arc are applicable to braze welding [9]. Figure 6 shows the appearance and the macrostructure of cross sections of dissimilar lap joints of industrial pure Al (A1050) to steel (SPCC) welded by MIG arc brazing with flux cored Al-Si alloy wire using a conventional DC pulsed MIG arc welder [11]. Development in filler wire will enable braze welding to be applied to joining other dissimilar metal combinations.

Practically, joining of this dissimilar combination is performed mainly by solid-state process such as friction welding and explosion welding, but limitations in the joint shape and joining conditions are large drawbacks. FSW is expected to be another possible process to make dissimilar metal joint in both butt and lap joints

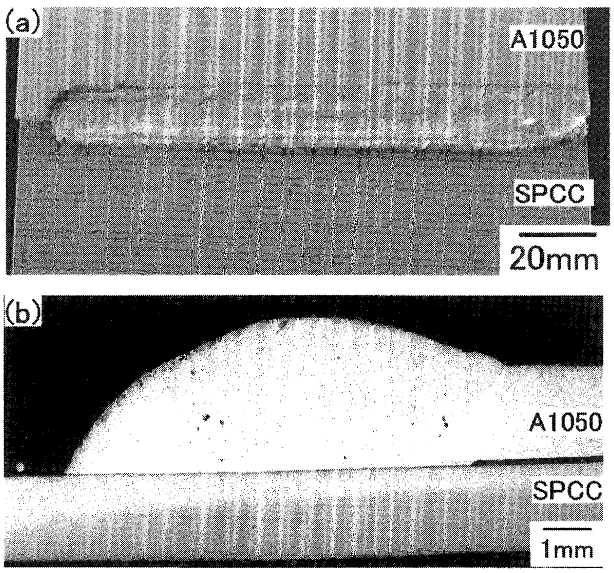

Fig. 6 Successful dissimilar metal lap-joint of A1050 Al to SPCC steel sheets by MIG arc brazing using flux cored Al-Si electrode wire; (a) appearance and (b) microstructure in cross section of welds [11].

by stirring only the Al alloy to bond it to the steel interface, resulting in a continuous joint [12].

3.2 New Functional Materials

In some newly developed materials, searching for suitable joining and welding processes has been carried out for construction of engineering component of the products. However, getting a continuous joint such as arc welding is not easy, thus the development of new joining and welding processes are desired as well as the modification of weldability of new materials themselves.

3.2.1 Porous metal

Recently, aluminum metal foam is anticipated as an absorb material for impact energy, and for noise and heat isolation as well as a lightweight material. For this purpose applicable welding methods have been discussed. For example, Figure 7 shows the macrostructure in cross sections of MIG arc welds of Al sheet sandwich foams. In this case each sandwich sheet of Al alloy is welded as shown in (a), and also welded to Al alloy plate in (b) [13], because direct welding of aluminum foams is difficult due to the large reduction in volume by melting cell structures [14-15]. Lotus-type porous metals with long cylindrical pores are a new type and also interesting as engineering materials [16-17]. Their welding methods will be required [18].

3.2.2 Ultrafine-grained metal

It is well known that grain refinement can increase the strength of the metals by the Hall-Petch effect without loss of the toughness. Ultrafine-grained steel with one micrometer or less grain size has high strength up to 800MPa and high toughness even with the same composition of 400MPa class steel [19]. Similar development has been continued in Al-base and Cu-base materials. The intention is to apply these fine grained metals as structural material, and a welding technology is inevitably needed, but is not established yet because of grain growth in the HAZ resulting in softening. Laser welding [20] and FSW are the expected processes, but further modifications to suppress the grain growth in the welds are required as well as the development of applicable FSW tools and cooling systems.

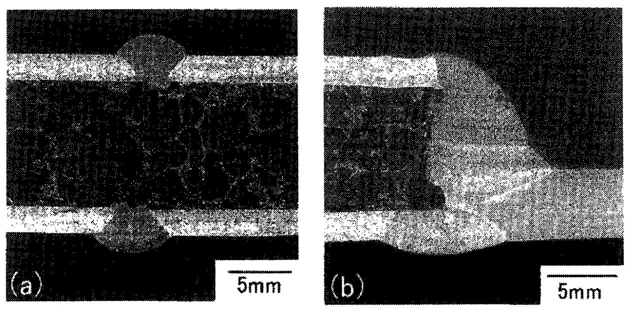

Fig. 7 MIG arc welds of Al sheet sandwich foams; (a) sandwich sheets were welded to each other, (b) sandwich sheet was welded to Al alloy plate [13].

3.2.3 High nitrogen steel

High nitrogen steels up to 0.3 to 1 mass% of nitrogen content possesses excellent corrosion and mechanical properties and are expected as structural materials [21]. However, some difficulties in the weldability of this type of steel are pointed out as shown in Fig. 8 [22]. This suggests that solid-state processes such as friction welding have high potential, though much limitation in the allowance of joint shape is inevitable.

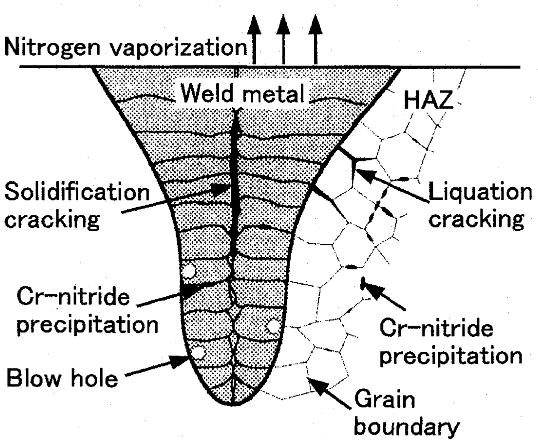

Fig. 8 Problems in fusion welds of high nitrogen steel [22].

3.2.4 Amorphous alloy

Good matching between new welding process and new functional material is typically seen in joining new amorphous alloy. Bulk metallic glasses, recently developed as a new type of amorphous alloy, can be fabricated directly from the melt in a bulk form with thickness of up to 10 mm at slow cooling rate in the order of 1 to 100K/s, and have a wide supercooled liquid region before crystallization with good workability [23]. These features of metallic glasses can solve the major problem inherent to amorphous alloy, namely lack of weldability due to crystallization of the welds, which results in the embrittlement. Prof. Kawamura et al have proved that bulk metallic glass can be successfully welded and keep original mechanical properties and amorphous structure by using electron beam welding and laser welding as well as friction, pulse-current and explosion weldings [24-25]. Welding processes with high energy concentration are applicable as can be illustrated by considering the relationship between cooling curve of each process and TTT curves of bulk metallic glasses as shown in Fig. 9 for $Zr_{55}Al_{10}Ni_5Cu_{30}$ and $Zr_{41}Be_{23}Ti_{14}Cu_{12}Ni_{10}$ for example. They also demonstrate successful dissimilar metal joining of $Zr_{41}Be_{23}Ti_{14}Cu_{12}Ni_{10}$ metal glass directly to metal Zr by electron beam welding as shown in Fig. 10, indicating good ductility of the welded joint [26].

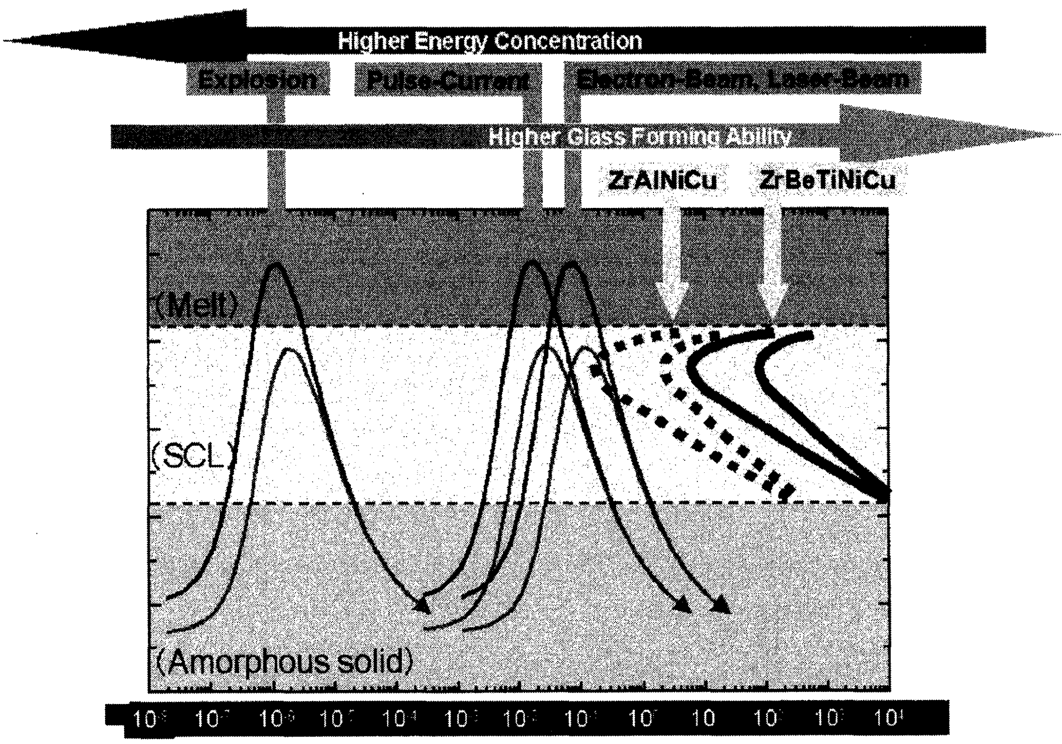

Fig. 9 Relationships between TTT curves of bulk metallic glasses (BMG) and heat cycles for corresponding processes [24].

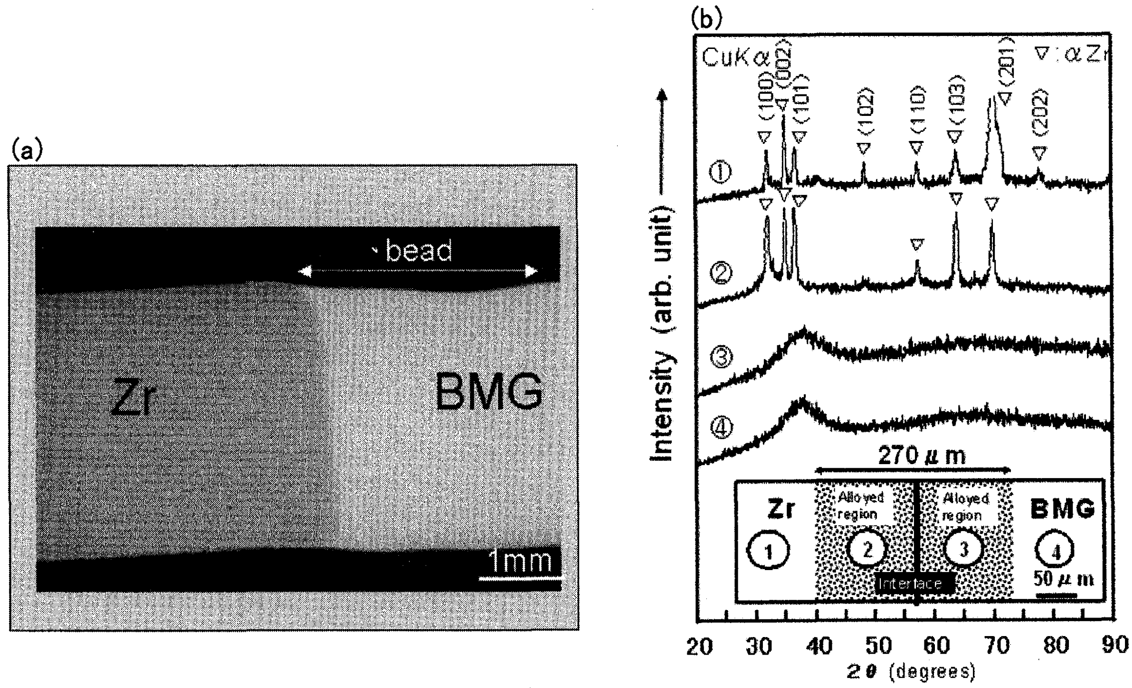

Fig. 10 Dissimilar metal joint of $Zr_{41}Be_{23}Ti_{14}Cu_{12}Ni_{10}$ metal glass directly to metal Zr by electron beam welding; (a) microstructure and (b) X-ray diffraction patterns in each position[26].

4. Conclusions

In this paper, the typical examples for the approach to solving the problems in joining and welding the new functional materials and the difficult-to-weld conventional materials have been reviewed in connection with new joining and welding processes, especially those capable of making continuous welded joints.

Solid-state joining processes and mechanical clinching have high potential, when joint configuration can be matched to the requirement of the products in spite of their limited allowance of joint configuration.

Finally, the author would like to express his thanks to the authors of the literatures referred to in this review.

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