Electron Beam Welding of Carbon Steel and Titanium Sheets Using Ag Insert Metal †

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Abstract

Electron-beam welding between low carbon steel and commercially pure titanium of 3mm thick sheets has been investigated using Ag insert metal. The effects of the thickness of Ag insert metal and the location of electron beam displaced onto either base metal on tensile strength of welded joint were investigated. Moreover, metallurgical investigations in weld metals such as distributions of Ti, Fe and Ag by means of EPMA and hardness distribution were discussed from the viewpoint of soundness in welded joint.

As a result, there were cleared, in order to make the sound joint of steel-titanium using Ag insert metal, that little melting of titanium base metal was one of the most important factor during welding and less than 15wt.% of Ti concentration should be kept in Fe-Ti rich layer of boundary between Ag-and Fe-rich zones in weld metal, and that for practical purpose the location of electron beam impinged was displaced by about the radius of electron beam onto the steel side from the edge of titanium base metal. The strength of steel-titanium joint using Ag insert metal showed about 30kg/mm^2 in tensile test by an adoption of the optimum welding condition.

1. Introduction

Electron beam welding process has many obvious advantages as compared with conventional arc welding. Of these the heat source of high power density, fine focus and controllability in location of electron beam impinged are the most beneficial advantage for welding of dissimilar metals. That is, in spite of a great discrepancy in physical and thermal properties between them they are easily welded by means of electron beam welding having a symmetric fusion zone, and they are also easily welded with an odd fusion zone when the location of electron beam impinged is consciously displaced from the seam line onto either base metal.

In the meantime, fusion welding by conventional arc methods between steel and titanium has been tried already and most of direct welding without any filler metal have been not succeeded for the sake of the occurrence of many cracks in weld metal during cooling after welding. The main reason for the cracking is considered that some brittle Fe-Ti intermetallic compounds which are formed in the weld metal due to mixing of molten iron and titanium in the puddle can not endure the shrinkage succeeding to welding.

Therefore, as regards conventional fusion welding between them, application of various insert metals has been examined, so far.[1–3] However there is only few report to have been published in case of arc welding within a limit of the author's knowledge. For brazing silver and its alloys are useful for filler metal and widely used to make the joint between steel and titanium.[4] In this investigation electron beam welding is applied to make butt welded joints of low carbon steel and commercially pure titanium 3mm thick sheets using pure silver insert metal. By changing the thickness of silver insert metal and displacing the location of electron beam impinged the weldability and the strength for the joints of steel-titanium were investigated.

2. Experimental Procedure

2.1 Materials used

The materials used in this investigation are as follows: (a) 3mm thick plain low carbon steel sheet (C:0.03, Mn: 0.19, Si: trace, P: 0.008 and S: 0.016%), (b) 3mm thick commercial pure titanium sheet KS 50 and (c) commercial pure silver foils of 0.3, 0.5, 0.8 and 1.0mm thickness.

2.2 Welding procedure

A high voltage type electron beam welding machine (maximum power 6KW, 150KV-40mA) was used throughout the investigation. The joint profile for butt welding between steel and titanium sheets using Ag foil is shown in Fig.1 Ag foil, the dimension of which was 8mm in width and Wmm in thickness, was inserted between them. W was varied as 0.3, 0.5, 0.8 and 1.0mm. In order to make a welded joint without any defect in appearance there are protuberances of Ag foil on both top and back surfaces, the dimensions of which were decided from experimental results.

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The locations of electron beam impinged which were represented in the arrows were in the center of Ag foil and successively varied to both base metals. The dimensions of the locations displaced were 0.3+W/2 and W/2 onto the Ti side, the center of Ag foil and W/2, W/2+0.3 and W/2 + 0.6mm onto the steel side which were illustrated as A, B, C, D, E and F in Fig.1. The welding condition of electron beam is 150KV in accelerating voltage, 9 to 13mA in beam current, 100mm/min in welding speed and 0.96mm in beam diameter which was measured in slope-type welding test piece.[5] All the welding were done with a straight single run under a high vacuum of 10^{-4} Torr or less.

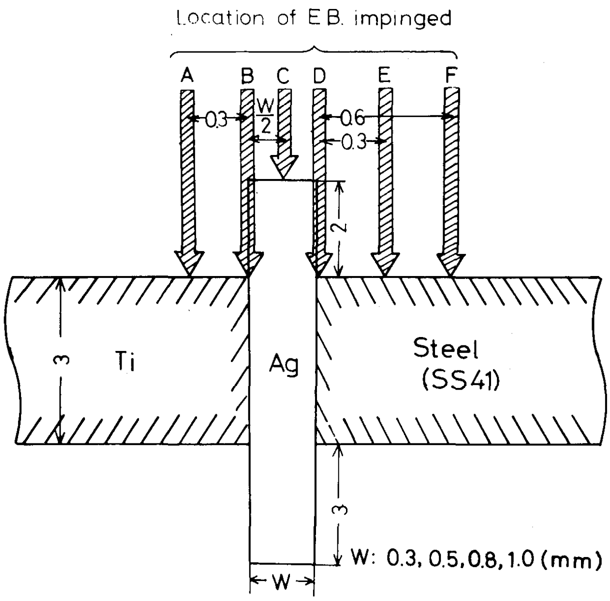

Fig. 1 Schematic illustration of joint profile

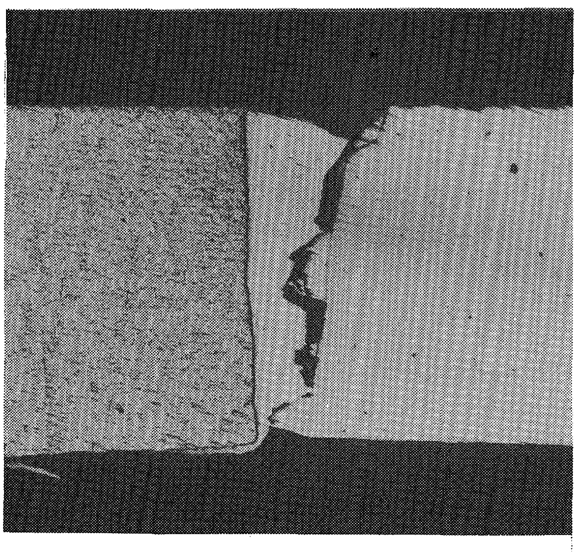

Fig. 2 An example of welded joint in cross-section after tensile tested

2.3 Testing methods

The welded joints were cut and machined all sides of welds in order to perform metallurgical and mechanical tests. Optical microscopic examination, hardness test and analyses of elements in the weld metal with EPMA were done as the metallurgical test and tensile test as the mechanical test.

3. Results and Discussions

3.1 Metallurgical test

A typical example of cross-sectional view of the welded joint is shown in Fig.2 after tensile tested. All the welded joints were fractured within weld metal. General schematic illustration of the weld metal in cross-section is shown in Fig.3. The weld metal is generally composed of three regions, that is, Ⓐ zone in Fig.3 is mostly from Ag containing 2 to 15 wt%Ti and 1 to 2%Fe, Ⓑ zone is mostly from Fe containing 1 to 2%Ti and Ag and Ⓒ layer which is located between Ⓐ and Ⓑ zones is several to ten-odd μm in thickness, and the composition of which is composed of Ti and Fe containing a small amounts of Ag, but the ratio of Ti and Fe is widely varied for each case.

Moreover Ⓒ layer is generally higher in hardness than Ⓐ and Ⓑ zones, and Ⓐ is the most soft because of Ag-rich zone. A typical example of metallurgical structure and hardness in knoop test is shown in Fig.4. The metallurgical characteristics of Ⓒ layer is the most important factor in order to make a sound steel-titanium joint using Ag insert metal. Ti element is the most concentrated in Ⓒ layer of the weld metal though the layer is apart from titanium base metal by Ag insert metal. An example of distribution of Ti and Fe elements near and in Ⓒ layer is shown in Fig.5. The peak

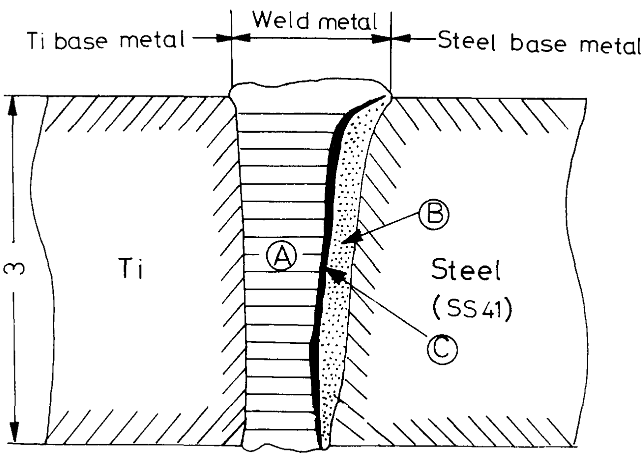

Fig. 3 Schematic illustration of welded joint in cross-section

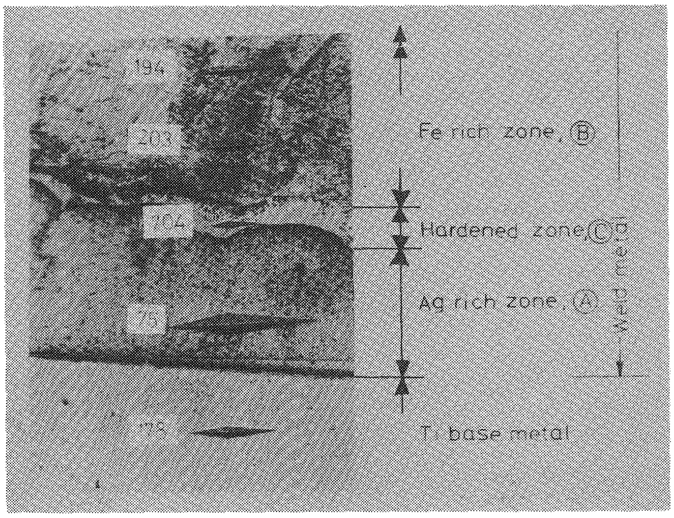

Fig. 4 Knoop hardness in welded joint

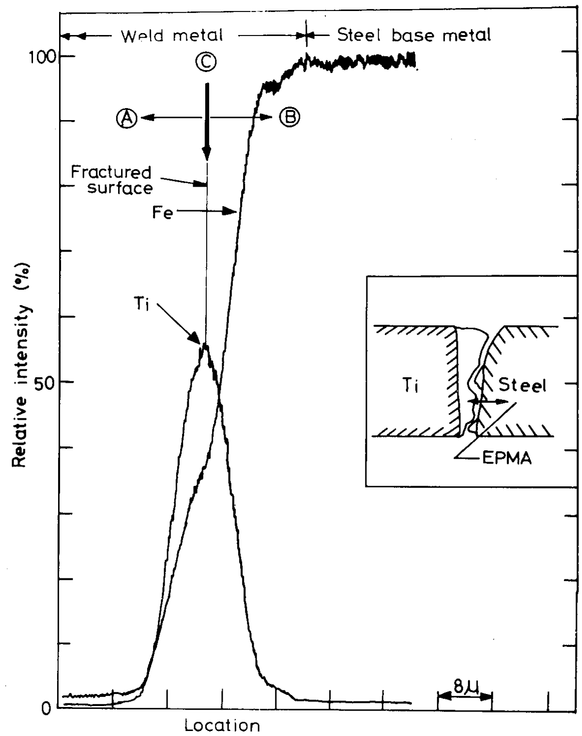

Fig. 5 An example of distribution of Ti and Fe elements near Ag-Steel interface

concentration of Ti element is shown in Ⓒlayer. This peak concentration is increased with an increase of the concentration of Ti element in Ag-rich Ⓐzone. That is, the more the melt of Ti base metal by electron beam, the higher concentration of Ti element in Ⓐ zone and moreover Ⓒ layer in general.

If the peak concentration of Ti element is high enough and some brittle intermetallic phase occur in Ⓒ layer, the welded joint may be brittle. There are two intermetallic phases $TiFe_2$ and TiFe in Fe-Ti binary alloy system as shown in Fig.6.[6)]

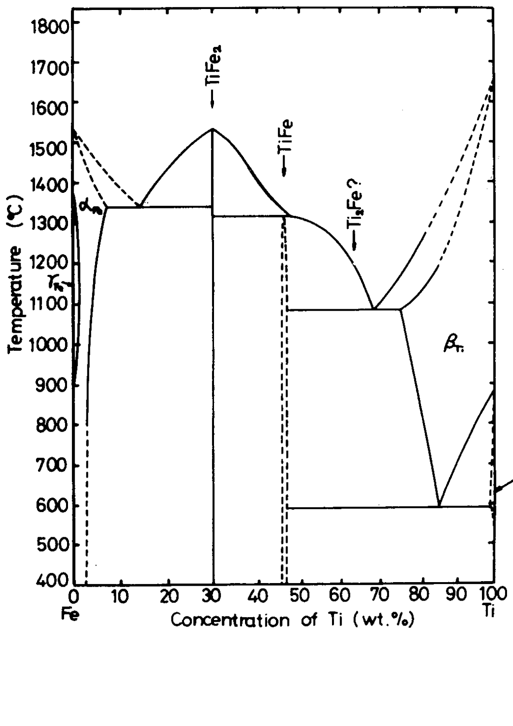

Fig. 6 Fe-Ti binary alloy system

3.2 Mechanical test

Effects of the location of electron beam impinged on tensile strength of welded joints are collectively shown in Fig.7(a), (b), (c), and (d) for various thicknesses of Ag insert metal. The arrow marks on the axis of abscissa in Fig.7 represent the location of electron beam impinged, respectively. Mark ● in the figures represents the tensile strength of the welded joints which were fractured in Ⓒlayer. Mark X represents that of the welded joints which were fractured in Ⓒlayer where penetration was poor because the location of electron beam impinged was far from Ⓒlayer. Mark ■ represents that of the welded joints which were fractured within Ag insert metal, that is, Ⓐ zone. Moreover mark ⊗ in (d) represents the welded joints which were fractured in the poor penetrated Ag-Ti interface.

In Fig.7 (a) using 0.3mm thick Ag insert metal the joints were weakened at 0.45mm on Ti side due to poor penetration in Ⓒ layer, and were widely scattered in strength at 0 and 0.15mm on steel side, but became stable in strength to about 25 to 35kg/mm^2 at 0.45mm on steel side. In Fig.7 (b) a stable strength for the welded joints is seen at 0.25mm on steel side in case of 0.5mm thick Ag insert metal. Moreover a stable strength is also predicted at between 0 and 0.4mm on steel side for Fig.7 (c) of 0.8mm in thickness and near 0mm for Fig.7 (d) of 1.0mm in thickness.

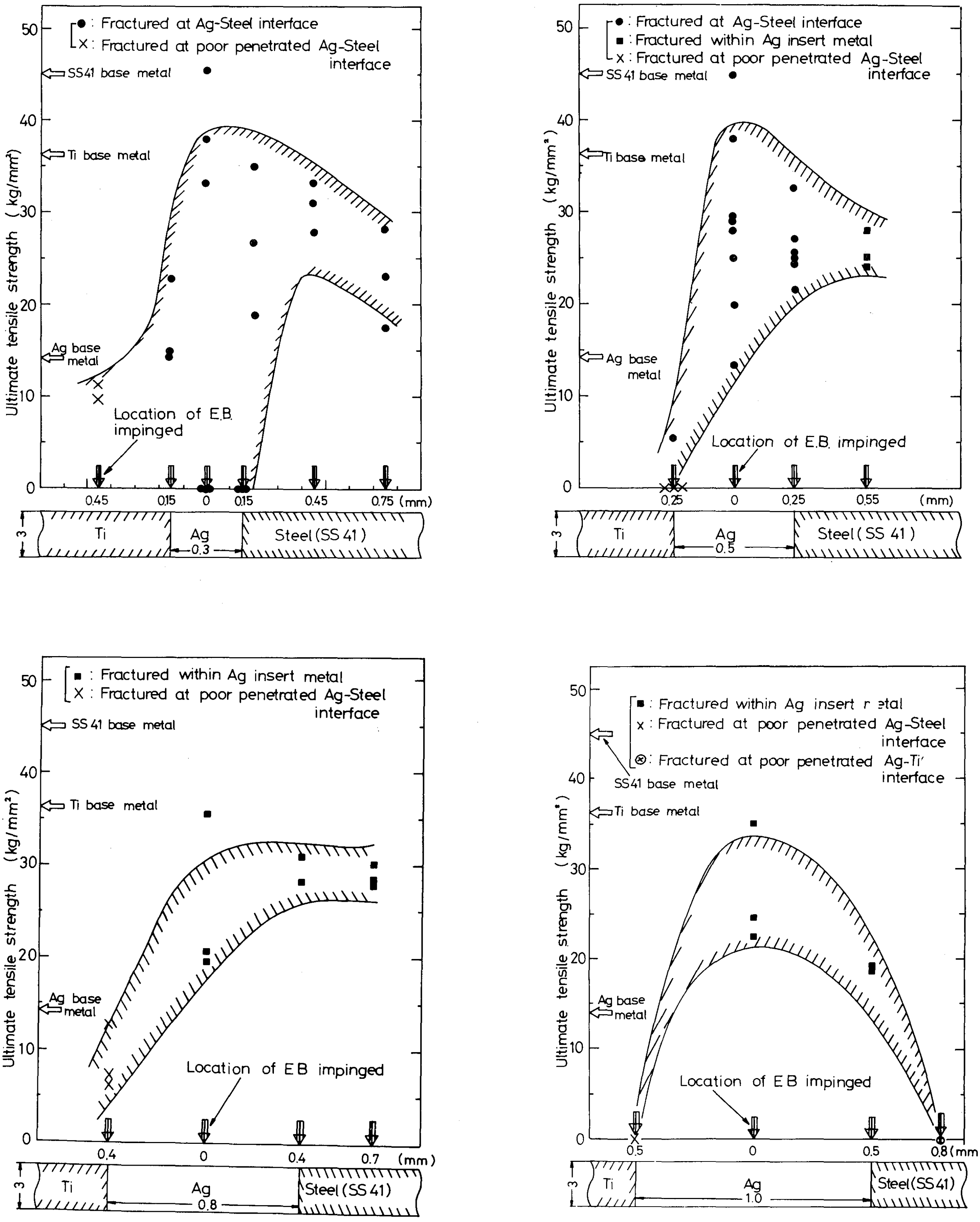

Fig. 7 Tensile strength vs. Location of electron beam impinged
(a) 0.3mm thick Ag insert metal
(b) 0.5mm thick Ag insert metal
(c) 0.8mm thick Ag insert metal
(d) 1.0mm thick Ag insert metal

Considering from these results and the beam diameter of 0.96mm, it can be concluded that, in order to have a stable joint strength, the location of electron beam impinged should be apart from the Ag-Ti interface by a distance of the beam radius or a little more. This means that the melting of titanium base metal should be as little as possible because the peak concentration of Ti element in Ⓒ layer is strongly affected. The effect of the peak concentration of Ti element in Ⓒ layer, which was measured with EPMA having about 2μm diameter of electron beam, on tensile strength of the welded joints is shown in Fig.8. It is concluded from Fig.8. that, in

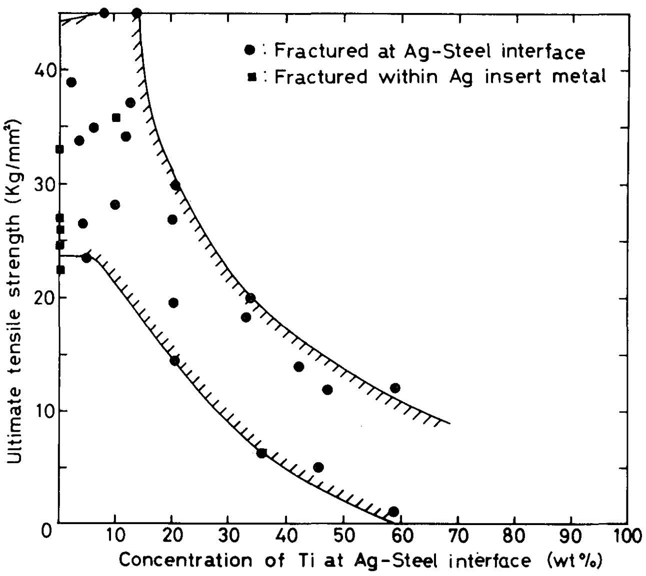

Fig. 8 Tensile strength vs. Concentration of Ti at Ag-Steel interface.

order to make the welded joint having more than about 25kg/mm^2 in strength, the peak concentration of Ti element in Ⓒ layer should be kept in the value less than 10 to 15wt% by taking care of excess melting of titanium base metal, and that when the value reach to 20% the strength of the joint would be reduced and become brittle.

4. Conclusions

Electron beam welding between steel and titanium 3mm thick sheets is investigated using Ag insert metal. The main conclusions obtained are as follows:

1) Weld metal with electron beam is mainly composed of three regions, that is, Ag-rich zone, Fe-Ti-rich layer and Fe-rich zone as shown in Fig.3 schematically.
2) There is the most metallurgical feature in the Fe-Ti-rich layer between Ag-rich and Fe-rich zones. The layer shows the hardest in hardness in the weld metal, often appears as intermetallic compound from its concentrations of Ti and Fe and shows brittle in mechanical property. It seems that the behavior of the layer is the most important in mechanical strength of the welded joint between steel and titanium sheets. When the peak concentration of Ti in this layer exceeds about 15wt%, the welded joint shows brittle and low strength in general. In order to make a sound joint, therefore, the peak concentration of Ti in this layer should be kept less than 15wt%.
3) So as not to increase Ti concentration in the Fe-Ti-rich layer, titanium base metal should be melted as little as possible. For the purpose of this it s recommended that a proper metal foil such as Ag is inserted between steel and titanium sheets and the location of electron beam impinged is displaced onto steel base metal.
4) In this investigation using Ag insert metal it was the optimum, in order to make a stable joint in strength, that the distance which was displaced from the edge of titanium base metal was about the radius of the beam, about 0.5mm or a little more. However the excess distance in displacing caused the lack of fusion in the boundary between titanium base and Ag insert metals. The thickness of Ag insert metal is recommended about 0.5mm in case of 3mm thick base metals in this investigation from economical and reliable standpoints. In the above case, therefore, the location of electron beam impinged is at the edge of steel base metal.
5) The tensile strength of 3mm thick steel-titanium welded joint using Ag insert metal is considered about 25 to 35kg/mm^2 when it is adopted the optimum electron beam welding condition.

Acknowledgement

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References

1) F.W.McBee, Jr., et al: W.J., 35 (1956) 10, 481-S
2) D. R. Mitchell, et al: W.J., 40 (1961) 12, 546-S
3) V. S. Golovchenko, et al: Svar. Proiz., 1971, 12, 36
4) D. Canonico, et al: W. J., 38 (1959) 2, 71-S
5) Y. Arata, et al: Trans. JWRI, 2 (1973) 2, 1
6) M. Hansen: "Constitution of Binary Alloys" NcGraw-Hill, 1958