NIPPON STEEL TECHNICAL REPORT No. 95 January 2007

UDC 669 . 295 : 621 . 791 . 754

Titanium Welding Technology

Tadayuki OTANI*1

Abstract

In order to establish titanium welding technology TIG arc weldability and MIG arc weldability were surveyed. For TIG arc weldability influence of arc length and thickness to proper region of welding condition became obvious. For MIG arc weldability a new method to defend wandering phenomenon was developed.

1. Introduction

Since titanium has excellent corrosion resistance, high specific tensile strength and good workability, it is widely used for automotive parts, heat-exchanger plates, etc. However, as far as the weldability of titanium is concerned, there are a number of problems that call for special attention. The reason for this is that when titanium is heated in the welding process, it easily combines with oxygen and nitrogen in the air and its mechanical properties deteriorate. Therefore, during arc welding of titanium in which the metal can be exposed to air, it is necessary to ensure that it is sufficiently shielded[1). By contrast, resistance welding (spot welding, seam welding), which does not cause the base metal being welded to be exposed to the air, can generally be applied to titanium. Since titanium has higher specific resistance than steel, it can be welded with a lower current. Furthermore, it does not impose any limitations on the welding equipment[2)]. This paper describes the application of TIG arc welding to titanium. TIG arc welding is the most popular form of arc welding and MIG arc welding, which is now being developed.

2. TIG Arc Welding

TIG arc welding is the most popular form of arc welding techniques applied to titanium. In TIG arc welding, where inert gas (e.g., argon) is supplied between the base metal to be welded and the high-melting-point tungsten to prevent exposure to air, an arc discharge is generated between them and the resulting heat is used to weld the base metal. The tungsten electrode and the base metal to be welded are connected to a DC power supply in such a manner that the former serves as the cathode and the latter serves as the anode. This is to facilitate cooling the tungsten from which electrons flow out and heating the base metal being welded into which electrons flow. With this arrangement, it is possible to restrain damage to the tungsten electrode and to efficiently melt the base metal.

2.1 Proper conditions for TIG arc welding

Fig. 1 shows the typical arrangement for the TIG arc welding of titanium. The primary difference from its application to steel is the shielding device. Since sufficient shielding effect cannot be obtained by the torch shield along the torch axis alone, it is necessary to provide an after-shielding device at the back of the torch to shield the high-temperature weld zone of titanium. It is also necessary to provide a back-shielding device to shield the back of the weld zone. For example, there are continuous titanium pipe production lines where the entire weld zone is sealed in a simple chamber to ensure sufficient shielding.

Fig. 2 shows the proper ranges of relation between welding speed and welding current in TIG arc welding of 0.5 mm-thick titanium sheet. Here, the arc length is 2 mm and the advance angle is 40˚. A tungsten electrode (lanthanum-containing, 3.2 mm in diameter) is used at a point angle of 40˚. The supplied shielding gas is argon—20 l/min for the torch shielding gas, 37.5 l/min for the after-shielding gas and 7.5 l/min for the back-shielding gas. A welding current that produced an uranami bead of 1 mm width was assumed as the low limit of the proper current range, and the welding current at which a burn-through was about to occur was assumed as the high limit of the proper current range. This corresponds to a surface bead width of about 3 mm. There is a positive correlation between welding speed and welding current. Namely, when the welding speed is increased, the proper welding current range shifts toward the higher-current side. When the welding speed exceeds 6 m/min, the molten pool can

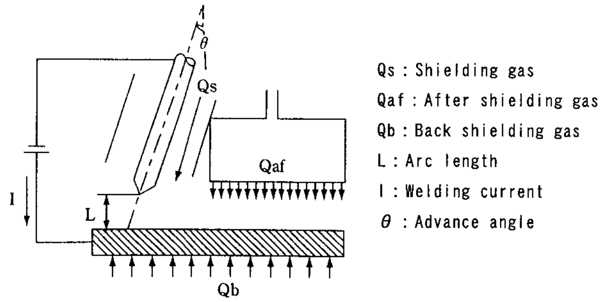

Fig. 1 Schematic diagram of TIG arc welding device of titanium

*1 Steel Research Laboratories

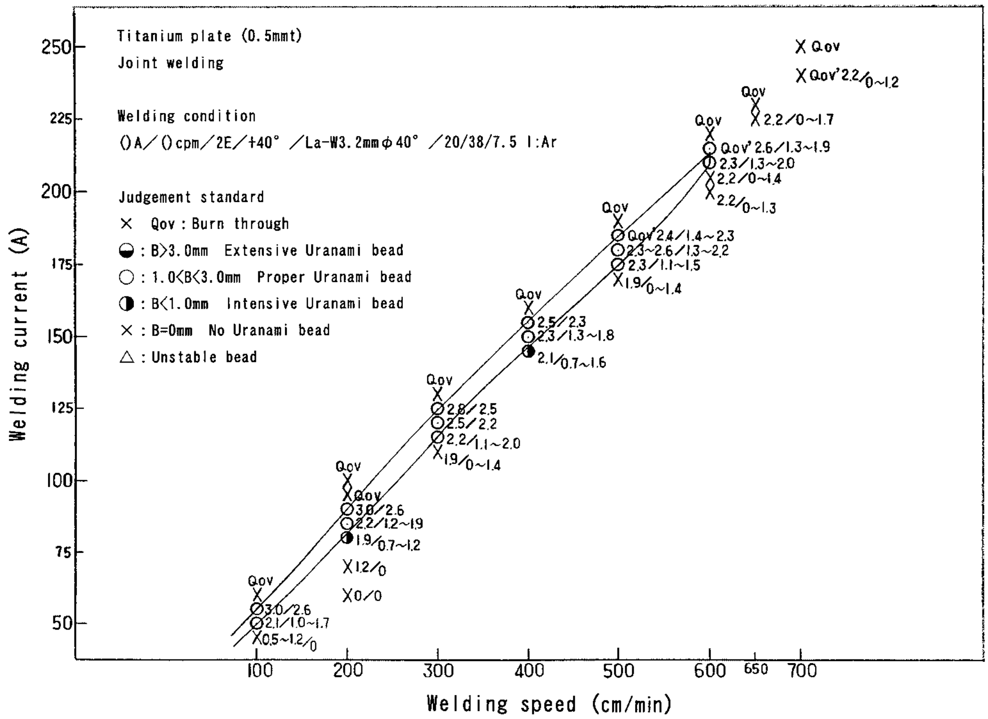

Fig. 2 Proper ranges of TIG arc welding condition (thickness 0.5mm, arc length 2mm)

no longer be maintained and the proper current range disappears.

2.2 Influence of arc length

Fig. 3 also shows the proper ranges of relation between welding speed and welding current in TIG arc welding of 0.5 mm-thick titanium sheet. Welding conditions are the same as those shown in Fig. 2, except that the arc length is 1 mm. When the welding speed is increased, the proper welding current range shifts toward the higher-current side. It should be noted, however, that the welding speed limitation is 7.5 m/min, higher by about 1.5 m/min than that shown in Fig. 2. The reason for this is that decreasing the arc length from 2 mm to 1 mm caused the arc to concentrate more, allowing for a larger uranami bead even at the same welding current. Another reason is

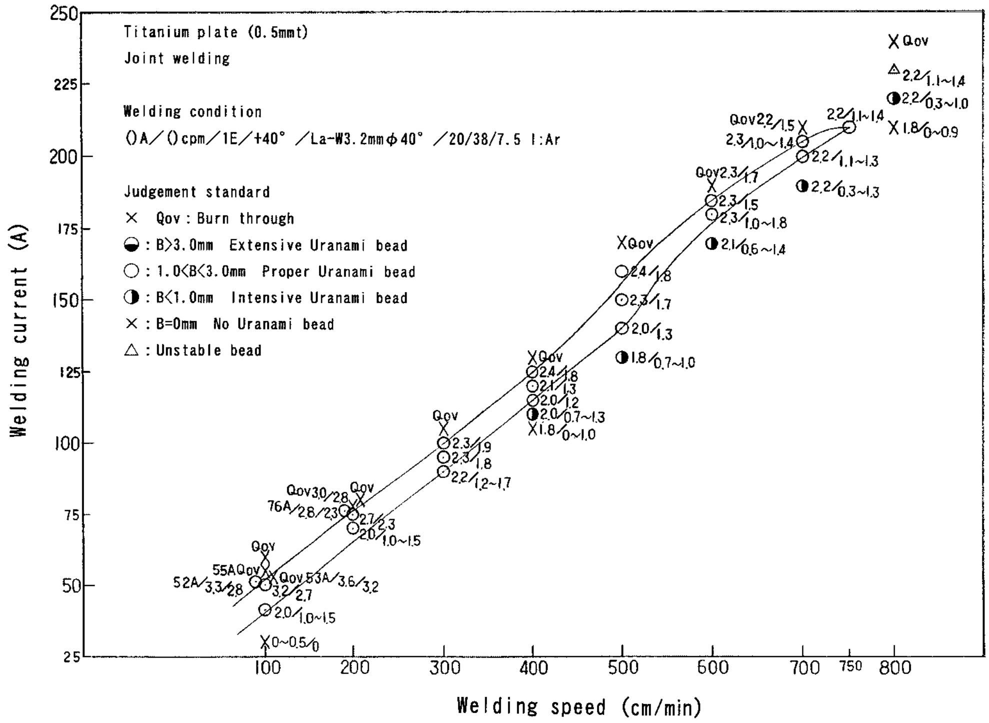

Fig. 3 Proper ranges of TIG arc welding condition (thickness 0.5mm, arc length 1mm)

that the shorter arc length also caused the surface bead width to decrease, thereby reducing the possibility of burn-through.

Now, the question is to what extent can we safely reduce the arc length. In this respect, we once performed TIG arc welding of titanium with an arc length of 0.1 mm. At that time, a very stable weld bead was obtained. However, with such a small arc length, if the molten pool becomes unstable due to some disturbance, the point of the tungsten electrode can be damaged by making contact with the molten pool. If this occurs, the possibility of unstable arc increases. In practice, therefore, an arc length of approximately 0.5 mm is considered the low limit. Thus, in TIG arc welding, controlling the arc length is extremely important since it significantly influences the welding results.

2.3 Influence of sheet thickness

Fig. 4 shows the proper ranges of relation between welding speed and welding current for TIG arc welding of 1 mm thick titanium sheet. The criteria for a proper welding current range are these: the current that produces an uranami bead 1 mm in width is the low limit, and the current that produces an uranami bead 3 mm in width is the high limit. As in the case of 0.5 mm-thick titanium sheet, there is a positive correlation between welding speed and welding current, the high-limit welding speed being 4.0 m/min. **Fig. 5** shows the proper ranges of relation between welding speed and welding current for 2 mm thick titanium sheet. In this case too, there is a positive correlation between welding speed and welding current, the high-limit welding speed being 1.0 m/min. Thus, with the increase in sheet thickness, the proper ranges of relation between welding speed and welding current become notably narrowed-down and the maximum (high-limit) welding speed decreases. A titanium sheet exceeding 2 mm in thickness can hardly be subjected to TIG arc welding in one pass. In this case, it is necessary to apply multi-pass TIG arc welding in which the base metal to be welded is previously subjected to edge preparation and a filler wire is fed during welding. TIG arc welding facilitates implementing high-quality welding of titanium. On the other hand, welding titanium sheet exceeding 2 mm in thickness is inefficient and costly.

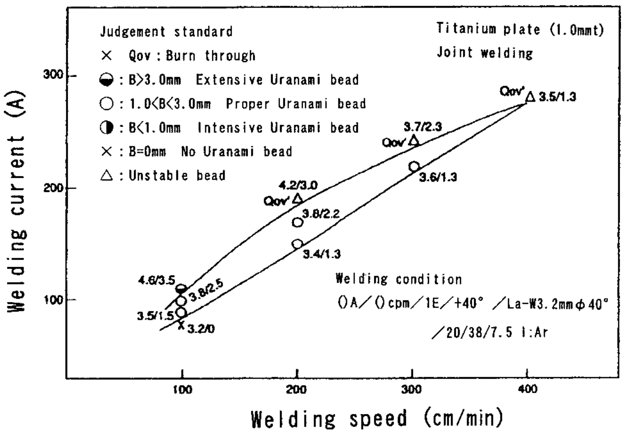

Fig. 4 Proper ranges of TIG arc welding condition (thickness 1mm, arc length 1mm)

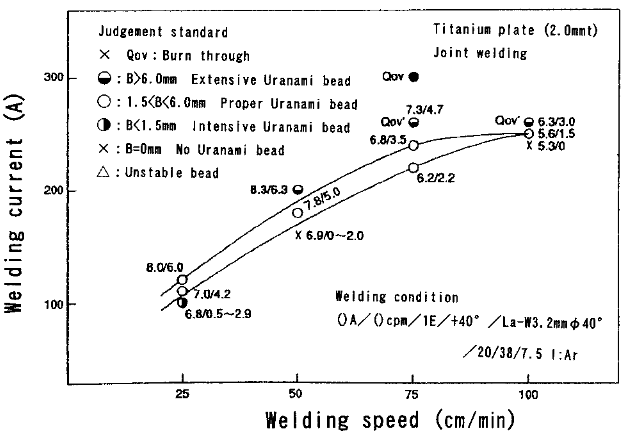

Fig. 5 Proper ranges of TIG arc welding condition (thickness 2mm, arc length 1mm)

2.4 Application of plasma arc welding

Increasing the energy intensity is an effective means of eliminating the above disadvantages of TIG arc welding. As shown in **Fig. 6**, a water-cooled nozzle made of copper is set in place between the tungsten electrode and the base metal to be welded and an arc is discharged through the hole in the center of the nozzle. With this arrangement, it is possible to obtain a plasma arc having higher energy intensity. When this plasma arc is used, even medium-thickness titanium sheet exceeding 2 mm in thickness can be welded in a single pass. It should be noted, however, that this welding technique requires more parameters to be set (including diameter of hole in nozzle, flow rate of center gas, distance between nozzle and the base metal to be welded, and the like) than TIG arc welding.

Fig. 7 shows the relation between the center gas flow rate and bead width, obtained when 3 mm thick titanium sheet was subjected to plasma arc welding (nozzle hole diameter: 2.8 mm, welding current: 210 A, nozzle-titanium distance: 2 mm, welding speed: 1 m/min). When the center gas flow rate is 0.5 l/min, no uranami bead is formed. As the gas flow rate is increased, the uranami bead begins to form. At the center gas flow rate of 1.5 l/min, the surface and uranami

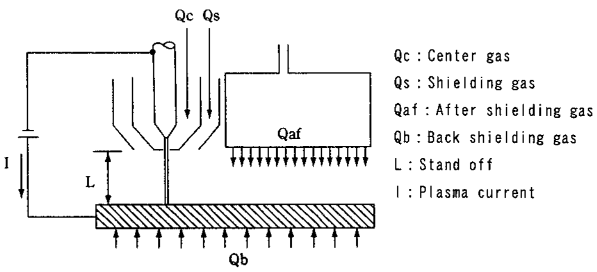

Fig. 6 Schematic diagram of plasma arc welding device of titanium

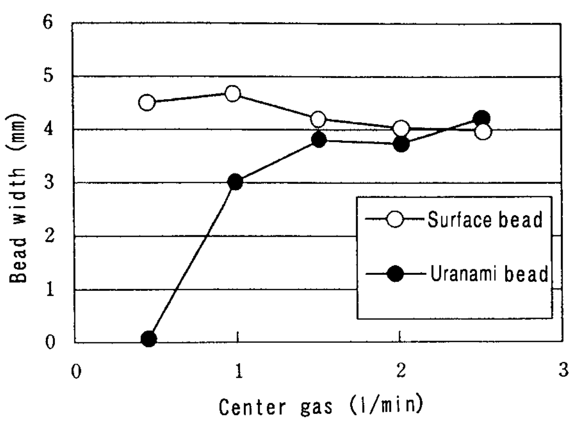

Fig. 7 Relation between center gas and bead width of plasma arc welding of titanium

beads become nearly the same width. Thus, by using a plasma arc having a high energy intensity, it is possible to perform one-pass welding of medium-thickness titanium plates up to approximately 10 mm in thickness to which TIG arc welding cannot be effectively applied. Nevertheless, plasma arc welding has not become widespread yet because there is considerable burden involved in setting welding parameters, and the demand for high accuracy of edge preparation, as well as other issues.

3. MIG Arc Welding

There is a need for an arc welding method which permits easy and efficient welding of medium-thickness titanium plates for structures. The authors considered MIG arc welding as a promising method that would meet this demand. The MIG arc welding method is one in which a consumable electrode (titanium wire) is continuously supplied and an arc is discharged between the point of the consumable electrode and the base metal to be welded (titanium), with the space between them filled with inert gas, so that the titanium is melted by the arc heat. In the case of TIG arc welding described earlier, the tungsten electrode is used as the cathode to prevent it from wearing. In MIG arc welding, the titanium wire is used as the anode and is capable of generating a large quantity of heat. Because of this, MIG arc welding allows for highly efficient welding with a high deposition rate.

In applying MIG arc welding to titanium, helium is normally used as the shielding inert gas. On the other hand, there is strong demand for argon as a substitute for helium since the former is less costly. When argon is used as the shielding gas, however, the arc can become unstable during welding. To resolve this problem, it is effective to mix approximately 2% oxygen in the argon. In this case, however, the mechanical properties of the weld metal deteriorate[3, 4]. Besides, the mixture of argon and 2% oxygen is more than twice as expensive as pure argon. Because of this, it has not become widespread yet. Although MIG arc welding is considered a promising method for welding titanium efficiently, the problem of arc stability remains.

3.1 Occurrence of wandering

As already mentioned, in MIG arc welding of titanium, the electrode (titanium wire) is used as the anode and the base metal to be welded (titanium) is used as the cathode. The surface of titanium is covered by a titanium oxide layer which tends to release electrons more easily than titanium. Because of this, electrons are released from every part of the titanium being welded. As a result, a phenomenon called wandering can occur. This is when the arc has a tendency to wander about. **Fig. 8** shows an example of a defective bead caused by wandering (welding current: 280 A, arc voltage: 26 V, welding speed: 0.6 m/min). One factor to be addressed in the development of MIG arc welding is how to restrain this unwanted phenomenon.

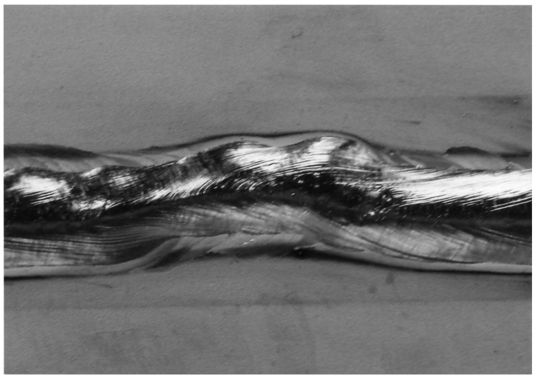

Fig. 8 Wandering bead of MIG arc welding of titanium

3.2 Improvement of MIG arc welding characteristic by application of high-frequency micro-oscillation

The authors attempted to derive a method which enables good results to be obtained from MIG arc welding using ordinary titanium wire as the electrode and argon as the shielding gas. After various experiments, it was found that the wandering phenomenon could be restrained for a few seconds by applying an impact to the welding torch system during MIG arc welding. On the basis of discussions on the physical effect of applying an impact to the welding torch system, it was concluded that the impact must have applied a damped oscillation to the welding torch system. Therefore, an oscillating device was fabricated that is capable of continuously vibrating the welding torch.

As shown in **Fig. 9**, the device made it possible to continuously apply a micro-oscillation to the torch in the direction perpendicular to the welding direction. It was found later that the oscillation was not "weaving" (amplitude: several mm, frequency: several Hz) which is commonly used in the welding field, but a high-frequency micro-oscillation which is effective especially when the amplitude is 1 mm or so and the frequency is tens Hz. **Fig. 10** shows the appearance of the oscillating device used in the present experiment. This device permits setting the amplitude of the tip of the welding torch to 0.5 mm, 1.0 mm or 1.5 mm. The frequency can be varied from 0 to 50 Hz. **Fig. 11** shows the appearance of a bead obtained by MIG arc welding of titanium (amplitude/frequency of oscillation of tip of welding torch: 0.5 mm/50 Hz, welding current: 280 A, arc voltage: 26 V, welding speed: 0.6 m/min). It can be seen that a very beautiful bead was obtained as the wandering phenomenon was restrained.

3.3 Effect of application of high-frequency micro-oscillation

As described in the preceding subsection, it is possible to obtain

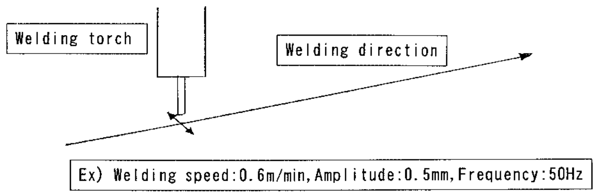

Fig. 9 Schematic diagram of high speed oscillation method of MIG arc welding of titanium

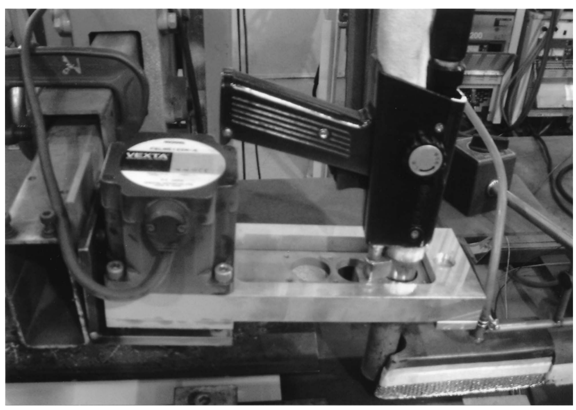

Fig. 10 High speed oscillation device

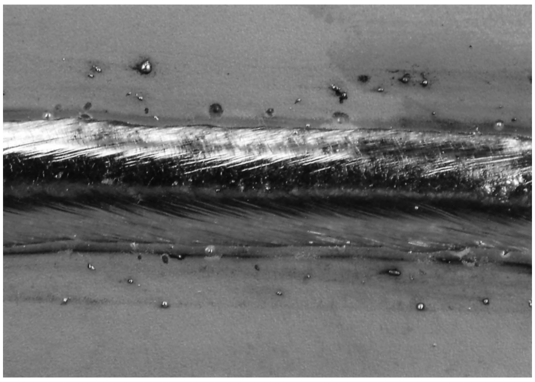

Fig. 11 Straight bead by high speed oscillation method

a good welding bead with a high degree of reproducibility by applying a high-frequency micro-oscillation to the tip of the welding torch in the MIG arc welding of titanium. In this subsection, the discussion focuses on the implications of this improvement in MIG arc weldability by application of a high-frequency micro-oscillation. At first, there were those that considered that applying a high-frequency micro-oscillation was an extension of weaving. However, since high-frequency micro-oscillation produces a satisfactory effect even at an amplitude of approximately 0.5 mm, it is evidently different from ordinary weaving. There was a then a study of the influence of the high-frequency micro-oscillation on the titanium wire-feeding characteristic. **Fig. 12** shows the arrangement of the experimental apparatus used to measure the titanium wire-feeding speed. The wire feed speed-measuring device with a built-in rotary encoder was connected to the conduit cable between the power supply and the oscillator.

Fig. 13 shows the time-serial change in titanium wire-feeding speed when an ordinary titanium wire was fed without high-frequency micro-oscillation. **Fig. 14** also shows the time-serial change in titanium wire-feeding speed when the same titanium wire was fed with a high-frequency micro-oscillation (amplitude: 1 mm, frequency: 15 Hz). It can be seen that without high-frequency micro-oscillation, the wire-feeding speed fluctuates noticeably. In contrast, the fluctuation of the wire-feeding speed is appreciably restrained by the application of a high-frequency micro-oscillation. Thus, it was found that the titanium wire-feeding characteristic is markedly improved by applying a high-frequency micro-oscillation to the tip of the welding torch in MIG arc welding. This suggests that the slide resistance of the contact tip at the conduit cable terminal governs the titanium wire-feeding characteristic. It was considered that when a high-frequency micro-oscillation was applied to the contact tip having a hole slightly larger in diameter than the titanium wire at the tip of the welding torch, the above slide resistance decreased and the wire-feeding characteristic improved, contributing to stabilization of the arc.

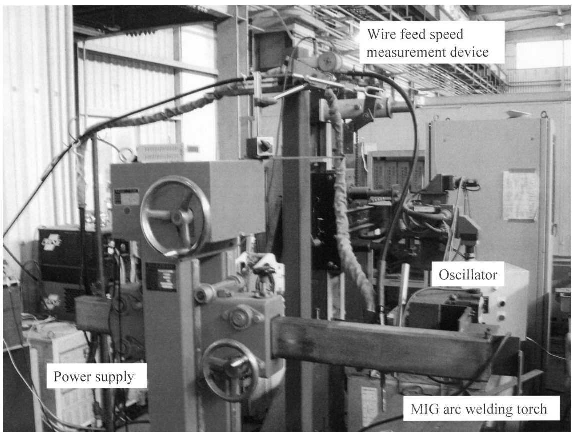

Fig. 12 Experimental apparatus of MIG arc welding with high speed oscillation method

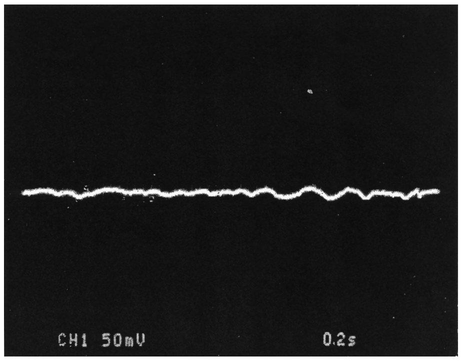

Fig. 13 Wire feed speed fluctuation of conventional MIG arc welding

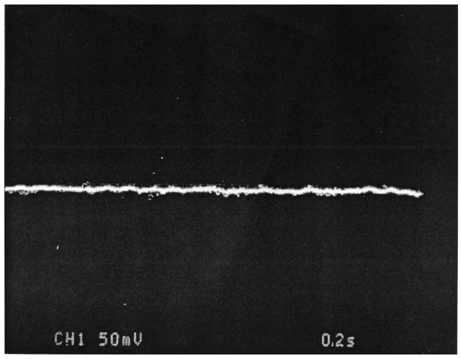

Fig. 14 Wire feed speed fluctuation of MIG arc welding with high speed oscillation method

4. Conclusion

The above described TIG arc welding and MIG arc welding as techniques applied to titanium. Concerning TIG arc welding, the influence of arc length and sheet thickness on the proper range of welding conditions was discussed. When TIG arc welding is applied to titanium sheet exceeding 2 mm in thickness, welding efficiency decreases because the welding operation must be performed in more than one pass. Therefore, the application of MIG arc welding was discussed as a highly efficient welding technique which permits welding medium-thickness titanium sheets exceeding 2 mm in thickness in a single pass. In ordinary MIG arc welding of titanium, a phenomenon called wandering occurs, whereby the weld bead wanders. It was found that this unwanted phenomenon can be restrained by applying a high-frequency micro-oscillation to the tip of the welding torch.

References

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