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The effect of welding conditions according to mechanical properties of pure titanium

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ABSTRACT

This study investigates the effect of welding condition according to mechanical properties of pure titanium and presents the optimum welding condition through the evaluation about the weldability of pure titanium by the welding conditions such as the welding pass, the amount of shielded gas and the welding time interval. In order to find out optimum welding condition by the mechanical properties of pure titanium, the annealed pure titanium of the ASTM B265 grade 2 is selected as a specimen and is classified by several welding conditions. And then, the experiments performed the test of tension, impact and hardness under the welding condition, respectively. The experimental result revealed that the specimen of 4-pass has the highest tensile strength in case of the welding pass condition. And, in case of the shielding gas condition, the tensile strength and elongation occurs the highest to the specimen of 25 l/min. The hardness value at the HAZ (heated affected zone) is higher than that for the WMZ (welding metal zone) and reveals almost the constant value more and more distance at the HAZ. Also, the impact absorption energy shows the high tendency by an increase in the number of pass.

1. Introduction

Machinery or structural joints are mostly riveted joints, screw joints or welded joints. With the development of welding technology, welding is used to make most structural joints. As the welding heats the base metal by generating high-temperature heat of 5000–6000 °C in a short period of time, the thermal expansion or cooling of the base metal results in thermoplastic deformation such as local bending and twisting. Welding structures usually fracture at the zones whose geometric shapes change rapidly, such as the weld reinforcement, toe area of the fillet welding and the fillet area of voids or an opening. Fracture also occurs as the conditions and environment at which the welding structure is used become worse along with the appearance of larger but lighter machines and structures. Therefore, it is necessary to check for cracks and residual stress that may reduce the fatigue strength of a welded zone to prevent welding defects. The mechanical characteristics of the weld such as yield point, tensile strength, hardness and brittleness should also be determined to make the optimum structure using appropriate welding conditions for the structure.

Safety and reliability of machinery should be secured in order to prevent the fracture of welded zone. For this reason, titanium is used increasingly because of its excellent specific strength (strength/specific gravity), light and very strong, high melting point, high fatigue strength and excellent corrosion resistance. Because its fatigue strength at high temperature can be maintained as 0.55–0.65 of the tensile strength, titanium is a promising, alternative material for lightweight car parts that require fatigue resistance.

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Table 1 – Chemical compositions of pure Ti specimen (wt.%)

Ti	O	Fe	N	H	C
Bal	0.144	0.03	0.006	0.002	0.002

However, it has a high affinity to gas and actively reacts to other elements or compounds at high temperature. If oxygen or nitrogen in the air infiltrates into the WMZ (welding metal zone), the hardness of the titanium welding would considerably increase but the elongation decreased. Therefore, welding of titanium requires complete gas shielding. It makes manufacture and testing of titanium complicated, and thus the research on titanium has not been sufficient so far.

Mechanical properties of a welded zone change from chemical reactions in the WMZ when filler metal is used, influx of impurities, dynamic solidification, and large inclination. Depending on the characteristics of the base metal, unexpected changes may occur. Also, a change in the chemical composition or structure of the base metal may reduce the strength or ductility of the base metal.

Especially, grains of the structure grow by the heat generated during welding. When the angle of groove that affects the strength of welded joint is small under the condition of full penetration, the tensile test and the bending test show better results, and less void and welding deformation occur. In the HAZ (heated affected zone), the grain size becomes coarse, and depending on the cooling conditions, the structure varies. Therefore, it can be said that the mechanical properties of the welding varies with heat treatment (Paris, 1976, 1963; Blaeslack and Banas, 1981; Mitohell and Feige, 1967; Kaneko and Woods, 1983; Lavigne, 1988; Schumacher, 1974; Compton, 1968; Chen, 1963; Nessler et al., 1971).

In short, the welded joint significantly affects the mechanical properties of the welded zone depending on the welding materials, welding conditions and welding environment.

This study investigates the effect of welding condition according to mechanical properties of pure titanium and presents the optimum welding condition through the evaluation about the weldability of pure titanium by the welding conditions such as the welding pass, the amount of shielded gas and the welding time interval.

2. Experiments

In order to evaluate the welding characteristics of titanium, pure titanium annealed with ASTM B265 grade 2 is used.

Table 1 lists the chemical compositions of the pure titanium used for this experiment and its mechanical properties are listed in Table 2.

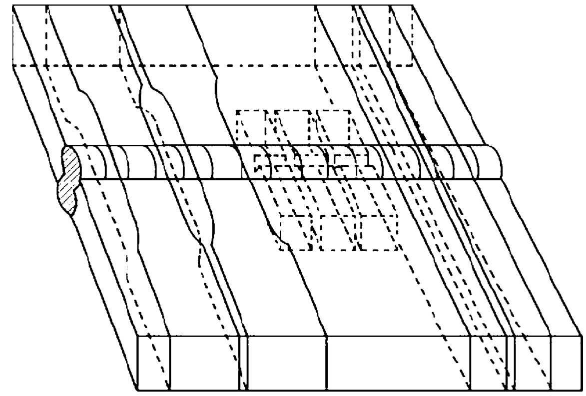


Fig. 1 – Location for the extraction of specimens.

To evaluate the weldability of pure titanium, its mechanical properties are evaluated at different welding conditions. To control the amount of heat input, the TIG welding machine is used.

The welding conditions are as follows; first, specimens are classified according to the amount of shielded gas: 15 l/min, 20 l/min and 25 l/min specimens; second, the specimens are classified according to the welding time interval and cooling time: 1-min, 3-min and 5-min specimens; and third, the specimens are classified according to the number of passes in the welded joint: 4-pass, 5-pass and 7-pass specimens.

Tables 3–5 list the welding conditions of the welding specimens. The shape of the welding joint groove of titanium is selected to be V when the thickness of the joint welding is 1.5–16 mm, and X or U when the thickness is 12–38 mm. When the welding condition includes the V-shaped groove, however, welding should be done on a single side. Then, deformation occurs and the bead width increases, which makes it to shielding the bead surface completely. And the deposition amount also increases, so more welding heat input is required, further deteriorating the mechanical properties. Therefore, we welded the specimen into the X-shaped joint groove.

To test the mechanical properties under each welding condition, tensile specimens, impact specimens and hardness specimens are prepared. As shown in Fig. 1, the titanium specimens at each welding conditions are extracted.

3. Result and discussion

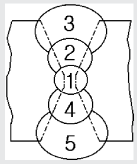
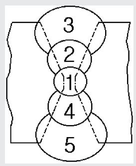
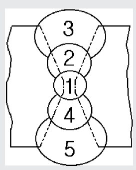
3.1. *Tensile test*

To evaluate the effects of welding conditions on the mechanical properties of pure titanium, the tensile test for each specimen is performed.

Table 2 – Mechanical properties of pure Ti specimen

Tensile stress (kgf/mm^2)	Yield stress (kgf/mm^2)	Elongation (%)	Young's modulus (kgf/mm^2)	Hardness (Hv)
40	49	28	10,850	119

Table 3 – Welding conditions of amounts of shielded gas

Welding type (l/min)	Shape of joint	Pass	Welding current (A)	Arc voltage (V)	Welding speed (cm/min)
15		1	140	15	4
		2	145	16	8
		3	130	14.5	5.5
		4	140	15	8
		5	130	14.5	5.5
20		1	140	15	4
		2	145	16	8
		3	130	14.5	5.5
		4	140	15	8
		5	130	14.5	5.5
25		1	140	15	4
		2	145	16	8
		3	130	14.5	5.5
		4	140	15	8
		5	130	14.5	5.5

The capacity of the tensile tester (United Model No. SFM-60) is 50 tonnes. The measured tensile strengths and elongations of the specimens indicated that fracture had occurred in the WMZ in all specimens.

Fig. 2(a) is the result of welding condition test according to the amount of shielded gas. For this test, the 25 l/min specimen displayed the highest tensile strength and elongation.

Fig. 2(b) shows the result of welding condition test according to the welding time interval. It is found that the longer the cooling time, the higher the tensile strength and elongation, which is not so significant.

Fig. 2(c) shows the result of tensile test according to the welding pass. It is found that the more welding pass, the higher tensile strength but lower elongation.

3.2. *Impact test*

The impact test according to the welding conditions is performed by the Charpy impact tester of 30 kgf m capacity.

Fig. 3(a) shows the absorption energy according to the amount of shielded gas. The 25 l/min specimen had the highest absorption energy. It is found that the less the amount of shielded gas, the less the absorption energy.

Fig. 3(b) shows the test result according to the welding time interval. The absorption energy hardly changed in the 5-min and the 3-min specimens, but was slightly lower in the 1-min specimen.

Fig. 3(c) shows the absorption energy according to the number of welding passes. The absorption energy was the highest

Table 4 – Welding conditions of welding time interval

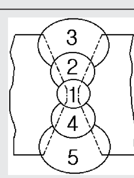
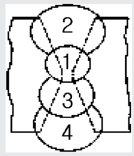
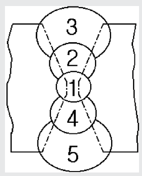
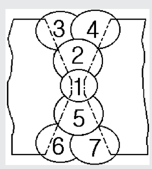
Afterpass (min)	Shape of joint	Pass	Pre-heating (□)	Welding current (A)	Arc voltage (V)
1		1	22	140	15
		2	270	145	16
		3	295	130	14.5
		4	325	140	15
		5	355	130	14.5
3		1	22	140	15
		2	132	145	16
		3	160	130	14.5
		4	165	140	15
		5	215	130	14.5
5		1	22	140	15
		2	124	145	16
		3	113	130	14.5
		4	125	140	15
		5	145	130	14.5

Table 5 – Welding conditions of welding pass

Welding type	Shape of joint	Pass	Welding current (A)	Arc voltage (V)	Welding speed (cm/min)
4-pass		1	140	15	4
		2	130	14.5	5.5
		3	145	16	8
		4	130	14.5	5.5
5-pass		1	140	15	4
		2	145	16	8
		3	130	14.5	5.5
		4	140	15	8
		5	130	14.5	5.5
7-pass		1	140	15	4
		2	145	16	7
		3	130	14.5	8
		4	130	14.5	8
		5	145	16	7
			130	14.5	8
			130	14.5	8

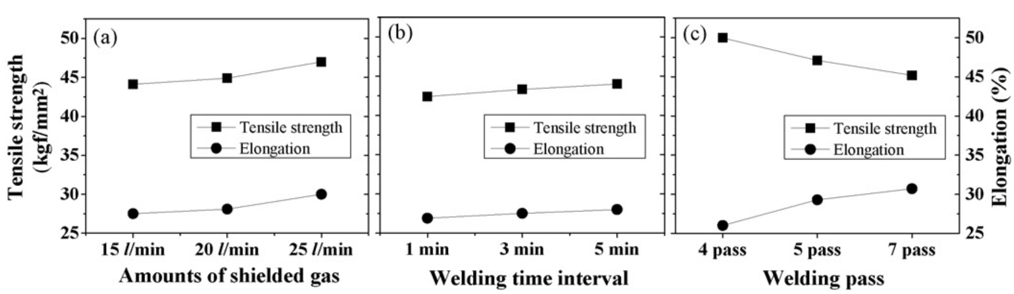


Fig. 2 – Results of the tensile test according to the welding conditions.

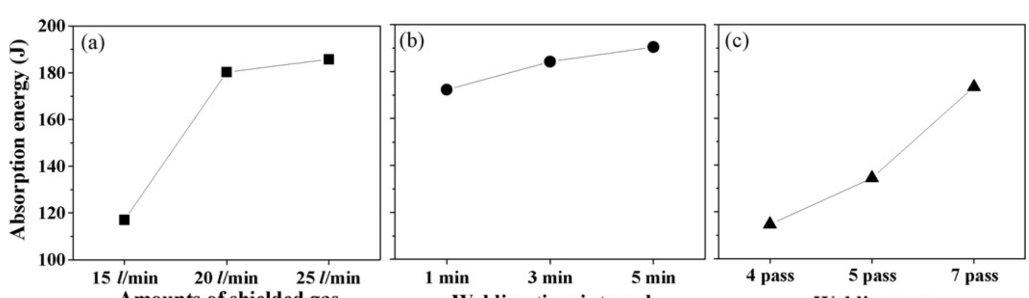


Fig. 3 – Results of the impact test according to the welding conditions.

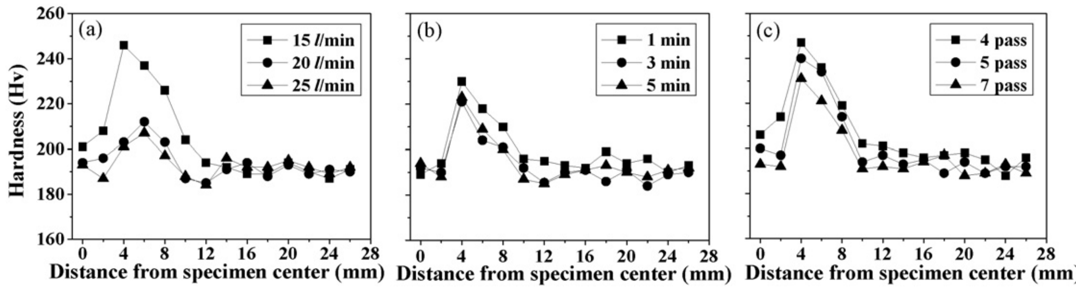


Fig. 4 – Hardness profiles cross the welding line according to the welding conditions.

in the 7-pass specimen. The absorption energy tended to increase as the number of passes increased.

3.3. *Hardness test*

To evaluate the mechanical properties of pure titanium as a welding material, we measured its hardness using the micro-vickers hardness tester, under the condition of 500 g load, test time of 30 s and interval of 2 mm. The measurement results excluded the maximum and the minimum value.

In general, the hardness of the welded zone was the highest in the HAZ, and such difference in the hardness was a major cause of the reduction of fatigue life of the welded zone.

Fig. 4(a) shows the distribution of hardness in the specimens according to the amount of shielded gas. The 15 l/min specimen had the highest hardness value, and 20 l/min and 25 l/min specimens had similar hardness values.

Fig. 4(b) shows the distribution of hardness according to the welding time interval. The distribution of hardness was the highest in HAZ.

Fig. 4(c) shows the distribution of hardness in the specimens according to the number of welding passes. The distribution of hardness was the highest in the 4-pass specimen, followed by the 5-pass specimen, and the 7-pass specimen. The hardness was much larger in HAZ than in the WMZ, and became almost constant as the measurement point moved away from HAZ.

4. Conclusion

(1) Under the welding condition according to the amount of shielded gas, the 25 l/min specimen (the most amount of shielded gas) showed the highest tensile strength and elongation. The cooling time after welding did not significantly affect the tensile strength and elongation. Under the welding condition according to the number of welding passes, the 4-pass specimen (the smallest number of welding passes) showed the highest tensile strength but the lowest elongation.

(2) The impact absorption energy was high when the number of welding passes was large and the amount of shielded gas was abundant. With respect to the welding time interval, the shorter the cooling time, the more the impact absorption energy.

(3) For each welding condition, the hardness value was high in the 15 l/min specimen, followed by the 1-min specimen, and the 4-pass specimen. The hardness was the highest in HAZ, and the difference in the hardness between HAZ and other zones was a major cause of the reduction of fatigue life of the welded zone.

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