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Scandium Effect on Mechanical and Physical Properties for 2x19 Al Alloy

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1. Introduction

Aluminum alloys possess an excellent combination of mechanical and physical properties. It is typical for aluminum alloys to contain grain refining element such as scandium and zirconium. Grain refining elements help nucleate grains during casting by forming intermetallic phases with aluminum. It was found that the addition of scandium and zirconium to 2xxx alloy resulted in $Al_3(Sc,Zr)$ particles and non-coherent insoluble phases.[1] These thermally stable dispersoids prevent or delay static recrystallization during processing. Based on this information, it was emphasized that mechanical and physical improvements can be realized for the 2xxx alloy system with scandium.[2,3]
The objective of the present research is to examine the effect scandium addition for 2x19 series alloy on the mechanical property, corrosion resistance and weldability in the base metal and in weld metal formed by MIG welding. And the scandium effect on microstructural behavior was investigated. The use of scandium enhanced the strength and ductility of 2x19 series alloys in both of base metal and weld metal. The scandium addition in 2x19 alloy affected the advantageous effect in weld metal and HAZ(Heat Affected Zone) due to the homogeneous distribution of inclusions and constituent particles to the fine grains. And the 2519 alloy containing scandium assessed the cruciform test which is one of the weldability test to confirm the stress corrosion resistance and cracking resistance. This extruded alloys as a plate form were performed the corrosion tests such as SCC (Stress Corrosion Cracking) test and EXCO(Exfoliation Corrosion)test. The result of this cruciform type of weldability test was very sound in ultrasonic test without cracks. And this alloy has good tensile property and excellent corrosion resistance in both area of base metal and weld zone. Such modified 2x19 type alloy containing scandium may be used to the aeronautical welding components and the structural armor plate of the light combat vehicles.

2. Experimental procedures

The chemical composition of the 2x19 Al alloy used in the present experiment is given in Table 1.

Table 1. Chemical composition of the 2x19 Al alloy.(Wt%)

Alloy	Cu	Mn	Mg	Zr	Sc	V	Ti	Fe
2519Sc	5.60	0.23	0.11	0.12	0.10	0.11	0.03	0.08
2519	5.60	0.23	0.11	0.12	-	0.11	0.03	0.08
ER2319	6.00	0.30	-	0.20	-	0.10	0.15	0.10

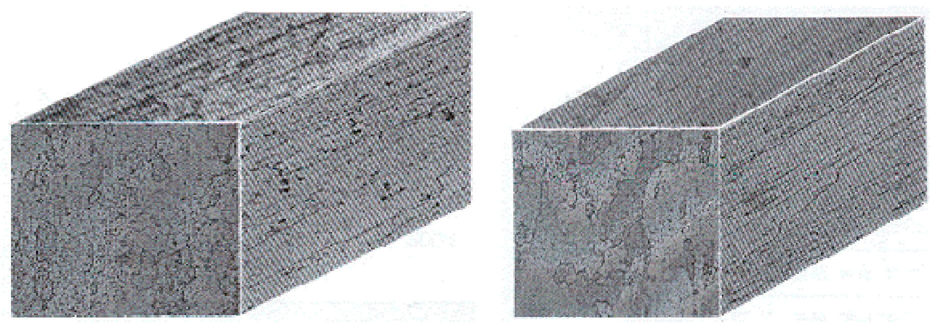
Billets of 2519 Al alloy containing scandium were homogenized for 16 hours at 490°C. Homogenized billets were extruded to plate form and rectangular bar. The reduction ratios for extrusion were about 18.5:1 and 17:1 respectively. After solution heat treatment for 1.5 hours at 535°C, stretching was conducted 2% above the yield point in order to reduce the residual stress. And artificial aging for T6 condition was conducted for 50 hours at 160°C.
The objective of 2x19 Al alloy containing scandium element is to have good mechanical and physical properties such as corrosion resistance and weldability due to the following characteristics[4,5]: 1) Grain refining elements such as Sc, Zr and V for 2X19 alloys help nucleate grains during casting by forming $Al_3(Sc,Zr)$ dispersoids in 10 to the 50 nanometer scale. These dispersoids and Al_2Cu phases enhance strength.[6,7] 2) These thermally stable dispersoids prevent or delay static recrystallization during processing. In addition, these dispersoids pin the elongated grain boundaries so that they inhibit recrystallization that would occur during the solution heat treatment step.
Tensile test was carried out at room temperature with constant crosshead speed of 2mm/min using Instron 4505 with cylindrical tensile specimens. Specimens for Charpy impact test were prepared according to ASTM E23 standard. The absorbed energies of the specimens during impact testing were measured by computer-aid instrumented Charpy impact test machine. Specimens for SCC(Stress Corrosion Cracking) test were C-ring type based on ASTM G38 and the testing condition was 230 MPa of applied stress for 10 days of exposure. SCC tests were processed by alternative immersion in 3.5% NaCl solution based on ASTM G47. EXCO (Exfoliation Corrosion) tests were conducted by continuous immersion in solution for 96 hours, which is based on ASTM G34.
To make the specimens, welding was conducted by MIG welding process using ER 2319 electrode without scandium under the condition of 75% He and 25% Ar gas, welding speed was 4.5~6.5mm/sec, current was 230~240 ampere and voltage was 28~29. The cruciform type corrosion test of the weldment to evaluate the weldability of HAZ was conducted by alternative immersion in 3.5% NaCl solution for 10 days based on ASTM G58.[8]

3. Results and Discussion

3.1. Matrix properties

3.1.1. Microstructure of matrix

Grain structures of the matrix are shown in Fig 1. Scandium containing 2519Sc alloy plate has more fine grain structure than the 2519 alloy plate without scandium.



(a) 2519 alloy **(b) 2519Sc**

Fig.1 Microstructure of the 2519 alloy and 2519Sc alloy.

3.1.2. Strength of matrix

Tensile strength of these alloys are shown in Table 1. The strength of the 2519Sc alloy is higher than one of the 2519 alloy because of the 2519Sc alloy having the uniformly distributed $Al_3(Sc,Zr)$ phases in nano- scale in diameter and having the equiaxed fine grains.

Table 1. Tensile properties of the alloys in T6 condition

Alloys		UTS (MPa)	YS (MPa)	El (%)
2519	L	462.3	345.0	21.4
	T	446.0	299.4	10.0
2519Sc	L	506.0	360.9	21.6
	T	458.1	345.3	18.1

3.1.3. Impact Energy

Impact energies of these alloys in T6 condition are shown in table 2. Absorbed energy of the 2519Sc alloy with scandium is 20% higher than the 2519 alloy for the refined grain structure and having higher strength. The 2519Sc alloy has higher value of impact energy because it has small amount of second phases and the well distributed inclusions with thin grain boundaries shown in Fig.1(b).

Table 2. Impact energies of 2519 alloy and 2519Sc alloy in matrix.

Alloys	Impact Energy (J)					
	TL orientation			LT orientation		
	Ei	Ep	Et	Ei	Ep	Et
2519	7.1	11.6	18.8	26.8	31.3	58.1
2519Sc	10.0	13.7	23.7	28.6	44.5	73.1

3.1.4. Fracture Toughness of matrix

Fig.3 shows the features of fracture surfaces of the fracture toughness test specimens of 2519 alloy and 2519Sc alloy with the type of straight through notch type respectively.

(a) 2519 alloy (b) 2519Sc alloy

Fig. 3 Fracture surfaces of the fracture toughness(K_{1C}) test.

K_{1C} test results of the 2519 alloy and 2519Sc are 48MPa√m and 50.7MPa√m respectively. 2519Sc alloy has the higher K_{1C} value compared to the 2519 alloy.

3.1.5. SCC(C-ring type)property of matrix

Fig. 4 shows that the scandium containing 2519Sc alloy is safer than the commercial 2519 alloy because of having the refined and equiaxed grain shapes. Applied stress to C-ring was 230MPa. Copper is the major addition element in 2xxx series aluminum alloy, but it is harmful element to corrosion resistance. So it can be the causes of pitting corrosion or exfoliation.

(a) 2519 alloy (b) 2519Sc alloy

Fig.4 C-ring test specimens after alternative immersion test of SCC.

Table. 3 Test results of C-ring test of matrix

Alloys	2519	2519Sc
Test duration	3 days	20 days
Results	Crack	No crack

3.1.5 SCC(EXCO) property of matrix

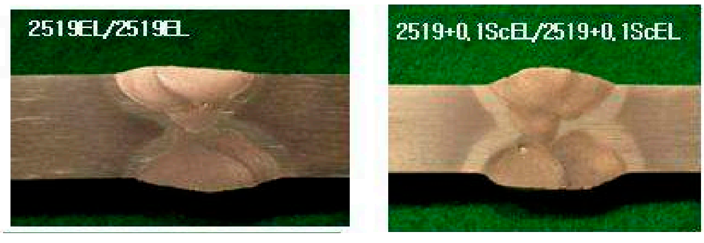
EXCO test conditions are as below, test solution is NaCl 4.0M, KNO_3 0.5M, HNO_3 0.1M, solution temperature is 25±3°C, specimen size is 50 by 100mm or equivalent, period of exposure is 96Hr, and cleaning should be done by rinsing in water and soaking in nitric acid.

Test results of EXCO of the 2519 alloy plate and 2519Sc alloy plate are comparatively sound, all the specimens have EA Ratings, which is the third rating among the 6 ratings like N, P, EA through ED .

3.2. Weld metal properties

3.2.1. Microstructure of weldment

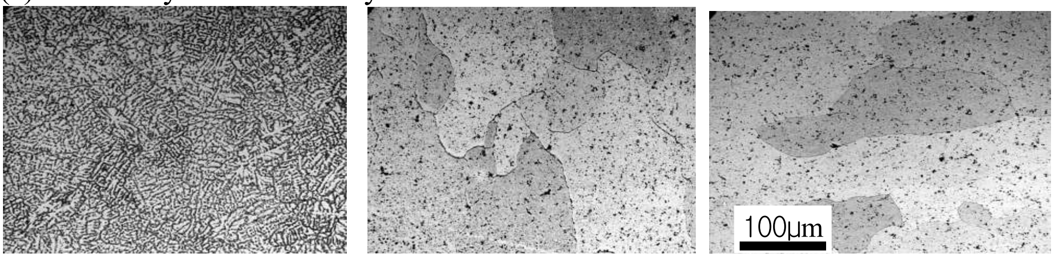
Fig.5 shows the cross section of welding joint of 2519 alloy to 2519 alloy and 2519Sc alloy to 2519Sc alloy in the longitudinal Plane. Fig.6 shows the microstructure of two samples of the weldments. 2519Sc alloy are finer than 2519 alloy in HAZ and matrix for the scandium addition effect. But the weld area of two weldments have the same cast structure.



(a) 2519 to 2519　　　　　(b) 2519Sc to 2519Sc

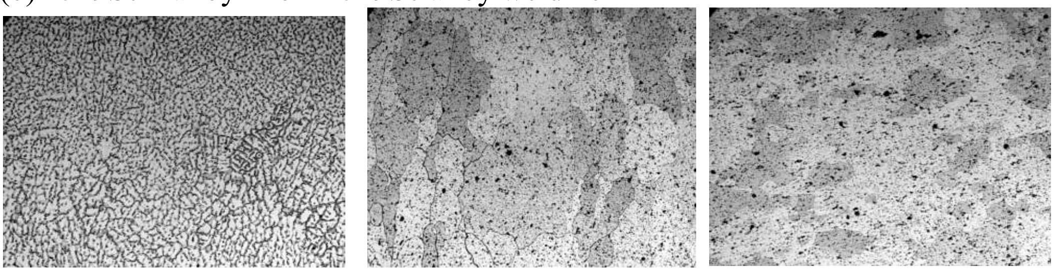
Fig. 5 Cross section of welding joint

(a) 2519 alloy to 2519 alloy weldment



Weld　　　　HAZ　　　　Matrix

(b) 2519Sc alloy to 2519Sc alloy weldment



Weld　　　　HAZ　　　　Matrix

Fig. 6 Photographs of the microstructure of weldment.

3.2.2. Tensile property of weldment.

Table 4 shows the tensile properties of weld area. 2519Sc alloy is stronger and more ductile than 2519 alloy because of the scandium bearing phases $Al_3(Sc,Zr)$ and grain refinement effect. Especially transverse property in ductility is double the percentage for the reason of distributing the second phases and inclusions in grain boundaries.

Table 4. Tensile properties of the weldment

Alloys		UTS (MPa)	YS (MPa)	El (%)
2519	L	290	175	8.0
	T	285	170	4.2
2519Sc	L	295	180	8.1
	T	310	175	9.6

3.2.3. SCC(cruciform type) properties of weldments

(a) 2519 to 2519 (b) 2519Sc to 2519Sc (c) specimen figure

Fig. 7 Cruciform type of SCC specimens

Table 5. Test results of cruciform type of SCC test.

Alloys	2519	2519Sc
Test duration	10 days	10 days
Results	No crack	No crack

Cruciform test were performed to assess the SCC characteristics of the weldment. Test results of the two type of alloys have the good resistance in cruciform type of high restraint form.

4. Conclusions

The current results demonstrate that physical properties of two alloys in matrix and weldment, one is scandium containing 2519Sc alloy, another is 2519 alloy without scandium. Scandium bearing 2519Sc alloy have better properties in all the test conditions for the reason of having the finer grains and having the new phase $Al_3(Sc,Zr)$. Therefore, the scandium bearing 2519Sc alloy is the one of the suggestions for the structurural aluminum alloy having good properties in matrix and weldment.

5. References

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