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Effect of Element on Porosity and Residual Stress Distribution of A7N01S-T5 Aluminum Alloy Welded Joints in High-Speed Trains

Yali Liu[1,a] , Jia Chen[1,b] ,Guoqing Guo[1,c *],Jiangli An[1,d],Hui Chen[1,e],

[1]School of Materials Science and Engineering, Southwest Jiaotong University, Chengdu 610031, China

[2]Chengdu Industry and Trade college,611731, China.

[a]15184362059@163.com,[b]15574423@qq.com,[c*]gouguoqing1001@163.com, [d]1559499460@qq.com, m,[e] xnrpt@163.com

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Abstract. In this paper, four types of A7N01S-T5 aluminum alloys with different chemical elements were investigated. Welded joints of the alloys were fabricated under 70%environmental humidity conditions at 10°C with single pulse GMAW welding technology. The alloys and their joints were tested and examined with impact toughness, porosities distribution and Synchrotron Radiation. The element results showed that the elements of Zn and Mg were the main factors that affect impact properties of the alloys. The #2 alloy which has the element of Zn-4.29 Mg-1.56 Mn-0.22 Cr-0.14 Zr-0.01 Ti-0.027 had the best impact properties which were 20.76J.The results indicated that the #2 had the lest stomatas only 22 and had the lowest porosity rate of 0.009% . Weld zone compared with the base material, the content of Mn and Ti had reduced.the#2 residual stress evenly distributed,the maximum tensile stress was 99Mpa in weld and the maximum compressive stress -66Mpa in base metal.forming .

Introduction

A7N01S-T5 aluminum alloy belongs to the Al–Zn–Mg alloy series. It has been widely used in high-speed train bodies and welding structures, such as corbels, beams and under frames due to its high strength, low density and good welding properties [1-2]. Porosity is one of the main defects produced in gas metal arc welding (GMAW) of aluminum–alloy structures during fabrication of high speed trains. Hydrogen (H) is the main contributor to porosity during welding . The solubility of H ions decreases as the temperature of the weld pool decreases during cooling. Thus, the H ions will escape from the weld pool during cooling by forming bubbles and floating to the surface. Bubbles that do not escape the weld pool become porosity. Research results conclude that porosity results a reduction in strength.

In addition to Al and the main alloying elements Zn and Mg, A7N01S-T5 alloy contains minority elements and impurity elements, such as Mn, Cr, Zr, Ti, Fe and Si. It has generally been recognized that alloying element and treatment determine the grain type, grain size, and distribution of precipitated phase, which affect the strength and fracture toughness of the alloy.Although extensive studies on one or two elements have been made to affect various mechanical properties and microstructural changes in Al–Zn–Mg alloys, published works on multiple elements of the same is rather limited. In this paper, the elements which have a similar effect on the properties would be taken into consideration as the same one factor. Therefore, it is important to understand the effect of elements on porosity distribution, impact toughness ,residual stress distribution of A7N01S-T5 aluminum alloy welded joints in high-speed trains.

Materials and experimental work

Four types of 8mm thick aged Al–Zn–Mg alloys (A7N01) with T5 aging were provided andnamed #1, #2, #3 and #4. The detailed composition were listed in Table 1. Welded joint samples were made by Metal Inert-Gas (MIG) welding method with PHOENIX 421 EXPERT welding machine with ER5356 welding wire with a diameter of 1.6mm. In order to remove the oxides and decrease the porosity of the joints, the surface of the base metal was chemical cleaned before the welding process. During welding experiments, 99.999% pure argon was used .The room temperature was 10 ℃ and the room humidity is 70%.The elements of the A7N01S-T5 base material and ER5356 are listed in Table 2.The welding technology was listed in Table 3.

Table 1 Base metal chemical element（wt%）

Sample **No.**	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Zr	V
#1	0.10	0.13	0.12	0.35	1.41	0.27	4.14	0.02	0.01	0.17
#2	0.08	0.14	0.11	0.28	1.56	0.14	4.29	0.02	0.01	0.17
#3	0.09	0.16	0.06	0.36	1.55	0.26	4.59	0.06	0.01	0.13
#4	0.11	0.26	0.28	0.35	1.56	0.26	4.60	0.07	0.02	0.14

Table2 Chemical element of ER5356 filler wire（wt%）

element	Si	Fe	Cu	Mn	Mg	Cr	Zn	other	Al
element	≤0.25	≤0.10	≤0.10	0.05-0.20	4.5-5.5	0.05-0.20	≤0.10	≤0.15	margin

Table 3 Welding process parameters

Material Type	thickness (mm)	Passes	Welding current(A)	Welding voltage(V)	Welding speed(mm/min)	Soldering Temperature（℃）	Welding humidity（%）
#1 #2 #3 #4	8	1	198-220	23.3-25.2	600-656	10℃	70%
		2	205-225	24.1-25.6	636-656		
		3	208-232	24.5-25.9	500-525		

The residual stresses evaluation of welded joints were evaluated using ultrasonic residual stress measurement. The measuring equipment is HT1000 residual stress evaluation machine, as shown in Fig. 1.

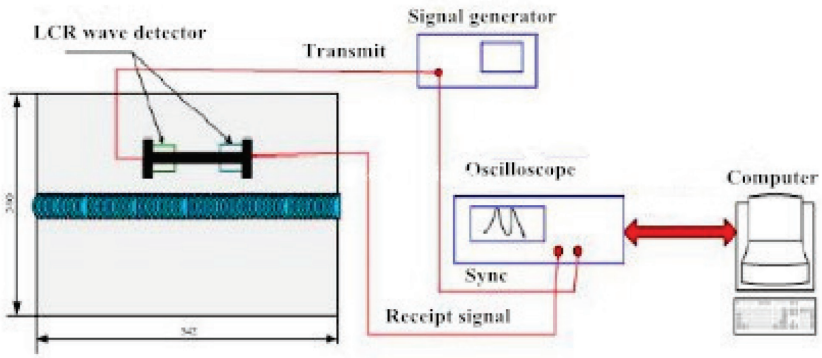

Fig.1Ultrasonicresidual stress measurement system

The samples that were used for optical microscopy observations were prepared by Keller reagent (1% HF + 1.5% HCl + 2.5%HNO3 + 95% H2O). The microstructures of the samples welded joints were examined using a Zeiss AX10 optical microscope. The cross sections of the welded joints first were examined using a VHX digital microscope and then the porosity quantity was analyzed with Image-Pro Plus software based on a color-difference analysis. method.

The residual stresses evaluation of welded joints were evaluated using ultrasonic residual stress measurement. The measuring equipment is HT1000 residual stress evaluation machine, as shown in Fig. 1.

Results and discussion

The impact toughness of the base metal and the weld zone are shown in Fig.2. The difference was tiny and the H#2 alloy had the highest Impact with 20.67J. The H#1 alloy had the lowest Impact ,lower 7J.

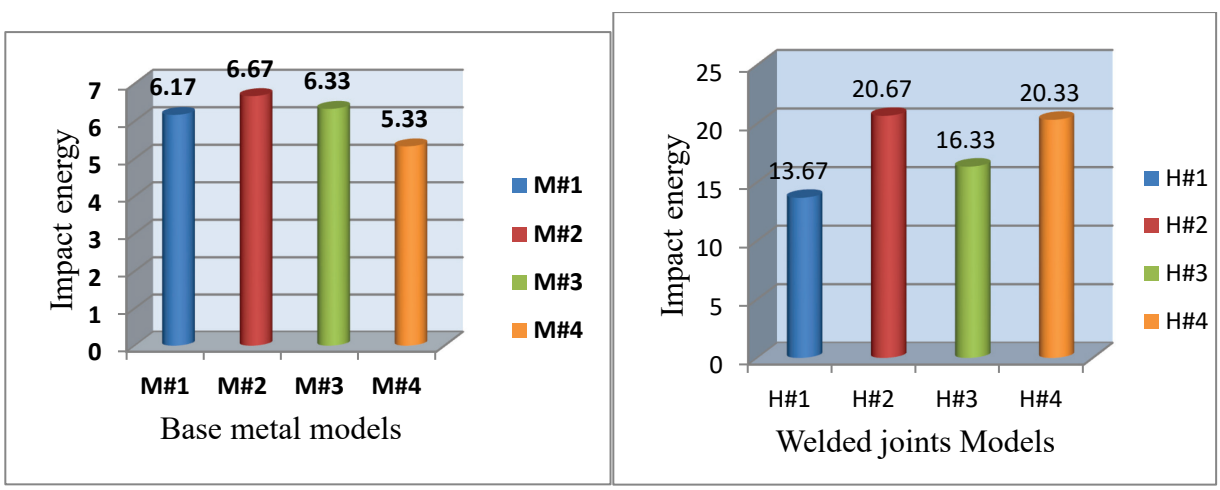

Fig.2 Impact energy of A7N01S-T5 alloy at various composition

By comparing the cross-sectional morphologies at various element.in Fig.3.The porosity quantity and area ratio of #2 were the lowest and the values of them were the highest in #3. From Fig.4, the concentration of Mn was apparently different between the weld and HAZ, and the concentration in the weld is lower than that of base metal. The reduction of Mn could lead to generate some harmful phases, e.g. b-AlFeSi phase with gray-needle shape, and Mg_2Si phase with black-striation shape, which usually can be found at the grain boundaries. Therefore, the mechanical properties can be

seriously affected by the vaporization of Mn. Ti can help to form $TiAl_3$ dispersion particles and refine the weld structure.

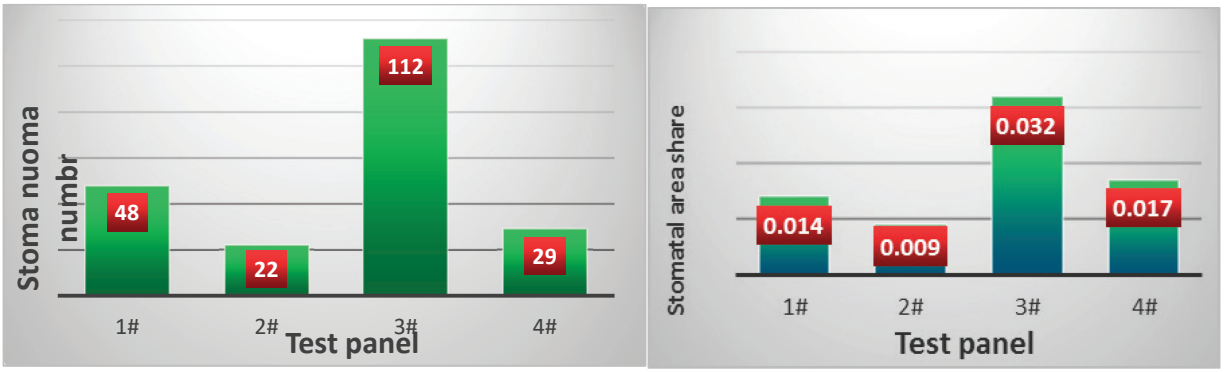

Fig.3 Porosity quantity and possession rate as a function of four samples(a) Porosity quantity(b) possession rate.

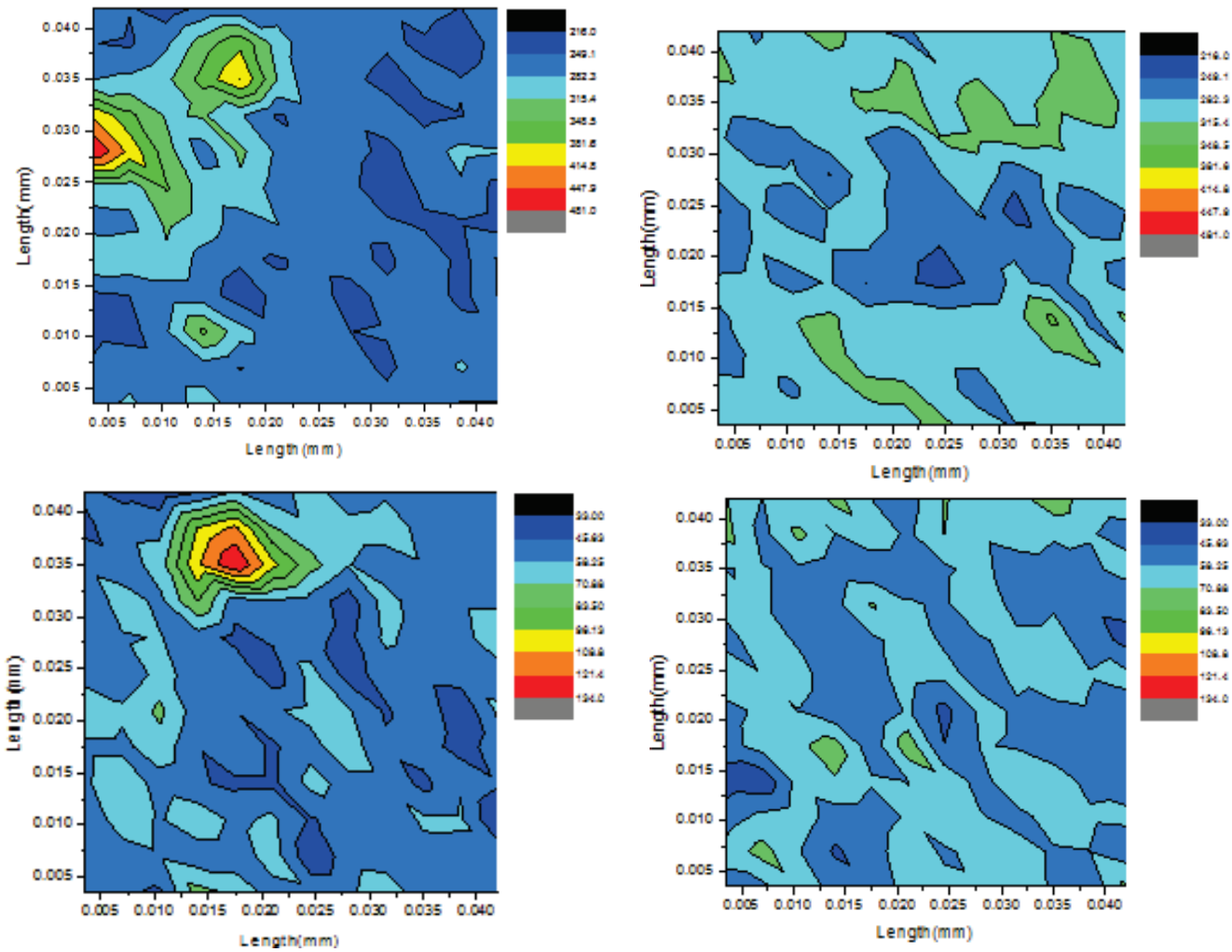

Fig.4 LXRF maps of elements inside base metal and joints, (a) Base metal element Mn, (b)Weld element Mn, (c)Base metal element Ti, and (d) Weld element Ti

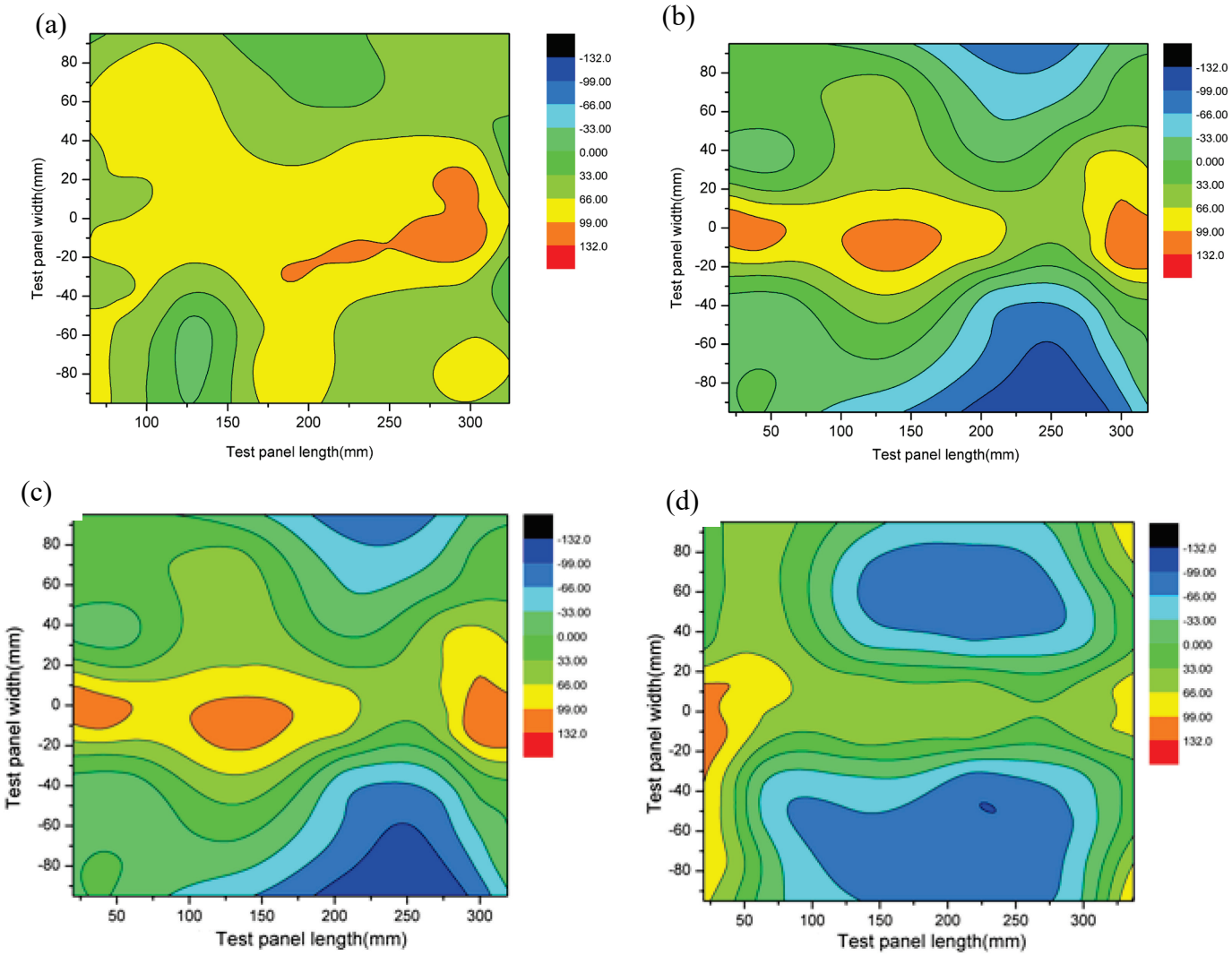

Fig.5 X axis the residual stress distribution of total area:(a)#1,(b)#2,(c)#3,(d) #4.

For # 1 and # 2, the area occupied by tensile stress is significantly greater than that by compressive stress. For #3 and # 4, the area of tensile and compressive stresses is quite different. the # 1 alloy maximum tensile stress was 132Mpa in weld, the maximum compressive stress was -33Mpa in base metal. The # 2 plate maximum tensile stress was 99Mpa in weld and maximum compressive stress -66Mpa in base metal. The 3# alloy maximum tensile stress was 120 Mpa in weld, the maximum compressive stress was -132Mpa in base metal. The # 4 alloy the maximum tensile stress is 66Mpa in weld, the maximum compressive stress -99Mpa in base metal.

Summary

(1)A7N01 different element of the alloy has a great influence on mechanical properties.Combination with welding defects and content of alloying elements can be found in the impact properties #2 sample is preferable.

(2) With the help of SR-lXRF, the distribution of these strengthening alloy elements in the base metal d and welded joint was obtained. From this distribution, the vaporization of Mn and Ti should also take responsibility for the different of the impact performance of the base metal and the welded joint.

(3)Under the same condition of welding surroundings and constraints.Different components of welded plates have different weld residual stress distribution.2# (Zn-4.29 Mg-1.56 Mn-0.22 Cr-0.14 Zr-0.01 Ti-0.027)stress distribution was evenly,the maximum tensile stress was 99Mpa in weld and the maximum compressive stress -66Mpa in base metal.

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