The Metallographic Analysis Optimization of Aluminum Alloy for Medical Equipment Parts

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Abstract: The purpose of this research is to study the metallographic analysis optimization of the T6-treated forging Al alloys, 7075, 6061, and casting Al alloy A356 for medical equipment parts. The influences of the metallographic image under several control factors, types of polishing solution, etching time, polishing speed, etc., are investigated. Taguchi method is employed to evaluate the optimization of aluminum alloy metallographic analysis. By using Matrox Inspector 4.0 image analysis software, the metallographic images are converted to gray scale. According to the gray scale values, the major factor of the metallographic image optimization for Al alloy 7075 and 6061 is the etching time, while the polishing speed is the least control factor. For Al alloy A356, the type of polishing solution is the main factor for the optimization of metallographic image, while the least influential factor is the etching time. The optimized metallographic factors combination can be used on the development and design of the medical equipment parts in the future.

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1. Introduction

In recent year, owing to the shortage of the energy supply, energy saving awareness has risen and the demand of light-weighted with high strength and high stiffness materials has increased. It has been recognized that alumina strengthened aluminum alloy metallic base composite material has good strength/weight ratio, especially its wear-resistant property is much better than that of strengthen base material. Since aluminum has very good anti-abrasive, mechanical and reusable properties, this type of materials have been widely used in medical equipment parts, general household, chemistry, aeronautics, aerospace, automobile and motorcycle. Due to the advanced of the technology and new materials development, metallographic research area has been broadened. Initially, metallography in coordinate with physical metallurgy focused on materials microstructure and metallurgical phenomena discussion and is hardly used in engineering applications. However, the progress of the metallographic technology has made this technology widely used at materials related production, machining manufacturing, medical equipment parts and material-breakage analysis [1][2][3][4][5]. Normally, chemical composition analysis and mechanical properties test are performed to understand the characteristics of an unknown material. However, simple mechanical property test (such as tensile, impact test) cannot show all material characteristic or defect. Metallographic analysis has become an important and direct test method to verify material characteristics.

2. Main content

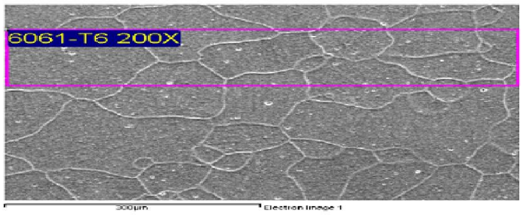
This project studies the optimization of the aluminum alloy metallographic analysis and discusses the factors that affect the metallographic image the most. Firstly, introduce three most effective factors (types of polishing solution, etching time, and polishing speed) into Taguchi method to perform the optimized metallographic analysis, and then use Matrox Inspector 4.0 image analysis software to analyze each group of metallographic images. After gray scale numerical statistic analyses, 0~ 255 gray scale peak values are chosen as Taguchi analysis data.

2.1 The choice of aluminum specimen

This study chose commonly used forged aluminum alloy 7075, 6061 and casting aluminum alloy A356 as test specimens to perform aluminum alloy metallographic optimization analyses. [5][6]

2.2 The design of Taguchi method

This study used Taguchi method $L_9(3^4)$ array structure to design metallographic analysis factors [7][8][9][10][11]. The control factors are: types of polishing solution (A), material etching time (B) and polishing speed (C). Each factor was set to three different levels. Table 1 and 2 show each factor, variation level and $L_9(3^4)$ array table. AxB is the interaction factor between polishing solution and materials etching time.



Element	Weight%	Atomic%
Al	87.33	87.76
Si	12.67	12.24
Totals	100.00	

Fig. 1 EDS composition analysis for Al alloy 7075

Table 1. Metallographic processing control factors

f	Parameter		Level 1	Level 2	Level 3
A	Polishing solution		Alumina 0.3 micro	Alumina 0.05 micro	SiO_2 0.06 micro
B	Etching time	7075	10s	20s	30s
		A356	28s	35s	42s
		6061	30s	40s	50s
C	Polishing speed		200 rpm	300 rpm	400 rpm

Table 2. $L_9(3^4)$ Array

EXP	A	B	AxB	C
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

2.3 The making of polishing solution

Reference Keller's etching solutions were adjusted properly and used as the aluminum alloy chemical etching solution in this study. Composition for both reference and adjusted solutions are shown in Table 3：

Table 3 Reference etching solution and adjusted etching solution

Keller's etching solution (reference)	*HF(1ml)+HCL(1.5ml)+HNO_3(2.5ml)+H_2O(95ml)* [1]
	HF(1ml)+HCL(1ml)+HNO_3(66ml) [6]
	HF(1ml)+HCL(1.5ml)+HNO_3(2.5ml)+H_2O(95ml) [11]
	HF(2ml)+HCL(3ml)+HNO_3(5ml)+H_2O(190ml) [12]
Adjusted Keller's etching solution	***HF(3ml)+HCL(1.5 ml)+HNO_3(2.5ml)+H_2O(93 ml)*** This is used as the aluminum alloy chemical etching solution in this study.

2.4 Aluminum alloy composition analysis

EDS of SEM was used to analyze the composition and element ratio of 7075, 6061 and A456 aluminum alloy to confirm that all the materials are qualified for the experiment.

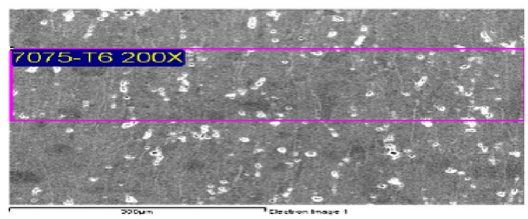
2.5 HV surface hardness analysis

Vickers hardness test was used to confirm the materials used in this experiment are T6-treated forging and casting aluminum alloy. 12 points were chosen on each series of the material. Each point was pressed for 10 seconds with 300g loading. Average hardness was calculated for comparison.

3. Experimental results

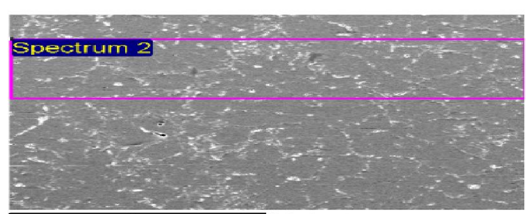
3.1 Aluminum alloy composition analysis results

Fig. 1 shows the result of Al alloy 7075 composition analysis; Fig. 2 shows the Al alloy A356 composition analysis result; Fig. 3 gives the composition analysis result for Al alloy 6061. All the results meet the industrial requirements.



Element	Weight%	Atomic%
Mg	2.42	2.81
Al	89.64	93.69
Cr	0.46	0.25
Cu	1.84	0.82
Zn	5.64	2.43
Totals	100.00	

Fig. 2 EDS composition analysis for Al alloy A356



Element	Weight%	Atomic%
Al	87.33	87.76
Si	12.67	12.24
Totals	100.00	

Fig. 3 EDS composition analysis for Al alloy 6061

3.2 HV surface hardness analysis results

Vickers hardness test was performed on aluminum alloy 7075, A356 and 6061. The results are shown in Fig. 4.

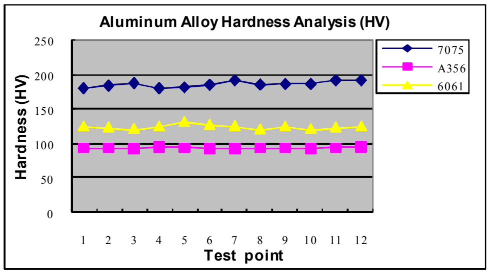


Fig. 4 Aluminum alloy HV hardness test results

3.3 Metallographic image gray scale value statistic analysis

Matrox Inspector 4.0 image analysis software analyzes each group of metallographic image. After gray scale numerical statistic analysis, 0~ 255 gray scale distribution peak values were chosen as Taguchi analysis data. (Gray scale with wider distribution and lower peak value has clear crystalline grain on its metallographic structure). Fig. 5 ~ Fig. 10 are the results of gray scale conversion of experimental data for three different aluminum alloy undergo Taguchi method test:

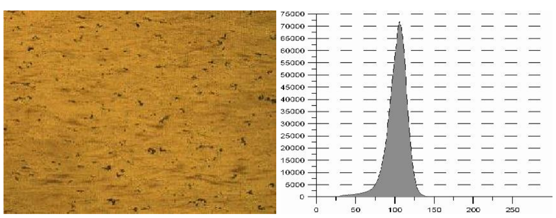


Fig. 5 Al alloy 7075 metallographic image (200X) and gray scale distribution curve (for Exp. No. 1)

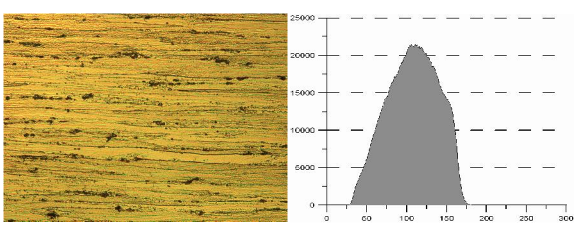


Fig. 6 Al alloy 7075 metallographic image (200X) and gray scale distribution curve (for Exp. No. 9)

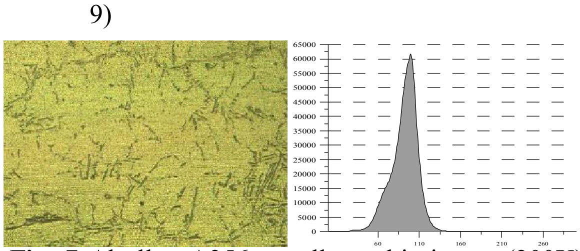


Fig. 7 Al alloy A356 metallographic image (200X) and gray scale distribution curve (for Exp. No.3)

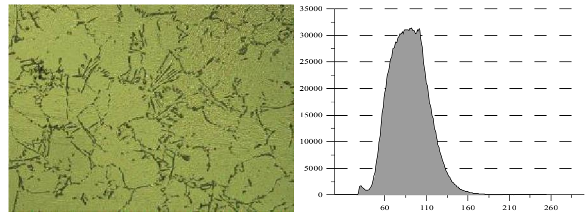


Fig. 8 Al alloy A356 metallographic image (200X) and gray scale distribution curve (for Exp. No.8)

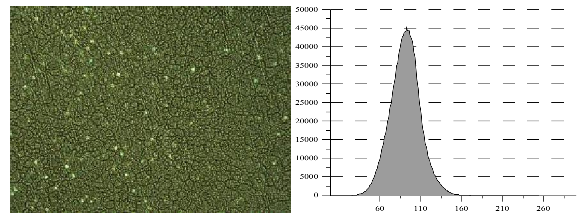


Fig. 9 Al alloy 6061 metallographic image (200X) and gray scale distribution curve (for Exp. No.1)

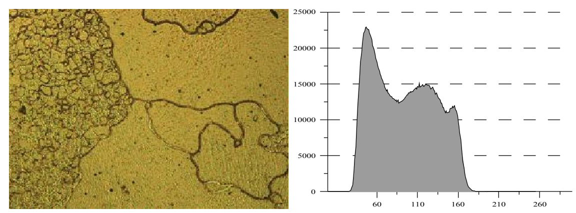


Fig. 10 Al alloy 6061 metallographic image (50X) and gray scale distribution curve (for Exp. No.10)

3.4 Metallography optimization analysis

Metallographic analyses were done based on factors level shown in Table 1; Matrox Inspector 4.0 software was used to perform image analysis. Gray scale with wider distribution and lower peak value has clear crystalline grain on its metallographic structure. This characteristic agrees with STB (the smaller the better). Fig. 11~13 show the S/N ratio results. The optimized factors for Al alloy 7075 metallographic analysis are A2, B3 and C1; For Al alloy A356 metallographic analysis, the optimized factors are A2, B3 and C1. The optimized factors for Al alloy 6061 metallographic analysis are A3, B3 and C3.

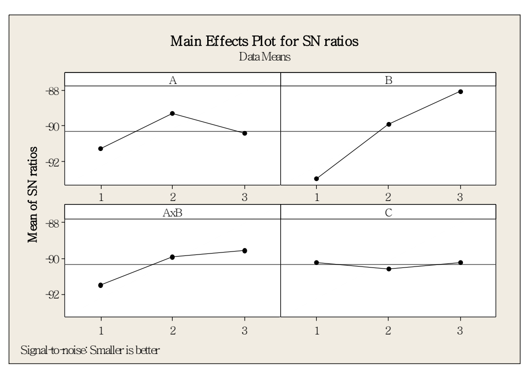


Fig. 11 S/N ratio plots of gray scale for Al alloy 7075

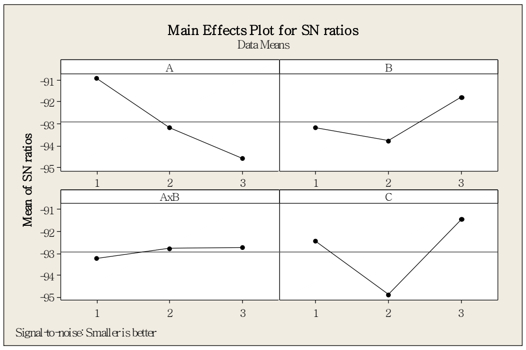


Fig. 12 S/N ratio plots of gray scale for Al alloy A356

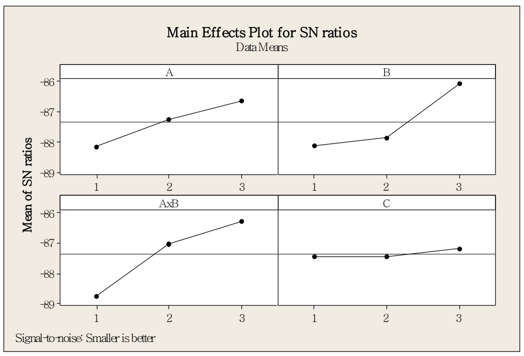


Fig. 13 S/N ratio plots of gray scale for Al alloy 6061

3.5 Metallographic gray scale variance analysis

Substitute S/N ratio into variance analysis calculation formula to perform the gray scale variance analysis to understand the optimized degree of contribution of each control factor on metallographic analysis. Analysis results are shown in Table 4 ~ Table 6. In Table 4, the major factor that affects Al alloy 7075 metallographic optimization is factor B (material etching time); In Table 5, the major factor that affects the metallographic optimization of Al alloy A356 is factor A (polishing solution); In Table 6, the major factor for the metallographic optimization of Al alloy 6061 is factor B (material etching time) if the factor AxB was not considered.

Table 4 Gray scale value variance analysis of Al alloy 7075

Factors	Degree of freedom *df*	Variation *S*	Variance *V*	Degree of contribution *ρ*
A	2	6.18	3.09	12.24
B	2	37.51	18.76	74.30
AxB	2	6.55	3.27	12.97
C	2	0.25	0.12	0.49
Total	8	50.49		100.00%

Table 5 Gray scale value variance analysis of Al alloy A356

Factors	Degree of freedom *df*	Variation *S*	Variance *V*	Degree of contribution *ρ*
A	2	20.55	10.28	44.35
B	2	6.13	3.06	13.22
AxB	2	0.43	0.21	0.92
C	2	19.24	9.62	41.51
Total	8	46.35		100%

Table 6 Gray scale value variance analysis of Al alloy 6061

Factors	Degree of freedom *df*	Variation *S*	Variance *V*	Degree of contribution *ρ*
A	2	3.45	1.72	16.68
B	2	7.48	3.74	36.21
AxB	2	9.59	4.79	46.41
C	2	0.14	0.07	0.69
Total	8	20.65		100%

3.6 Optimized metallographic analysis factors combination

The S/N ratios can determine the optimized metallographic analysis factors combination. The optimized combination factors are summarized in Table 7.

Table 7 Optimized metallographic analysis factors combination

Factor / Optimized comb. / Type	Polishing solution	Etching time	Polishing speed
7075	A2：Alumina 0.05micro	B3：30 s	C_1：200 rpm
A356	A1：Alumina 0.3 micro	B3：42 s	C_3：400 rpm
6061	A3：SiO_2 0.06 micro	B3：50 s	C3：400 rpm

4. Conclusion

(1)Matrox Inspector 4.0 software was used to perform image analysis. Gray scale with wider distribution and lower peak value has clear crystalline grain on its metallographic structure.

(2)The optimized factors for Al alloy 7075 metallographic analysis are A2(Alumina 0.05micro), B3(etching time 30 seconds) and C1(polishing speed 200rpm).

(3)The optimized factors for Al alloy A356 metallographic analysis are A1(Alumina 0.3micro), B3(etching time 42 seconds) and C3(polishing speed 400 rpm).

(4)The optimized factors for Al alloy 6061 metallographic analysis are A3 (SiO2 0.06micro), B3 (etching time 50 seconds) and C3 (polishing speed 400 rpm).

(5)The optimized metallographic factors combination can be used on the development and design of the medical equipment parts in the future.

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