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Effect of the Heat treatment on Mechanical and Physical Properties of Direct Recycled Aluminium Alloy (AA6061)

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Abstract: Products by solid-state recycling of aluminum chips in hot extrusion process were controlled by temperature related parameters using preheating temperature 450 °C, 500 °C, and 550°C for 1 hour, 2 hours, and 3 hours preheating time. By using Design of Experiments (DOE), the results found that the preheating temperature is more important to be controlled rather than the preheating time in analysis both mechanical and physical properties. The results also found that increasing of temperature led to the high tensile strength and low microhardness. The profile extruded at 550 °C with 3 hours' duration had gained the optimum case to get the maximum tensile strength and the profile extruded at 450 °C with 1 hour had result the optimum case to gain the maximum microhardness. For the optimum cases, heat treatment was carried out using quenching temperature at 530 ºC for 2 hours and aging process at 175 ºC for 4 hr. The tensile strength and microhardness of extrudes specimens were improved significantly by heat treatment.

Keywords: AA6061, tensile strength, hot extrusion, DOE, microhardness

1. Introduction

Aluminum production has been extensively used for many applications accordingly recycling of aluminum prompts a tremendous number of cost and environmental benefits. In every melting process of conventional aluminum recycling, many losses occur in metal oxidation and in slag mixing. Amount of the metal volume is missed by conventional recycling as a chip during the finishing process [1]. From this reason nowadays, an economical process has been discovered instead of conventional recycling, and this process involves the direct treatment of the chip of the metal [2]. The method of treating and collecting metal machining waste is called metal chip processing, which uses metal crushers, oil separators, drying of the chip, and other specialized equipment [3]. A direct recycling of aluminum alloy machining chips into finished or semi-finished product is an alternative method to overcome the issue of losing material by using remelting of aluminum chips and to additionally build up the energy balance of the aluminum production [4]-[6]. Aluminum as chips can be directly changed into semi-finished or finished items through mechanical operations, for example, hot extrusion, hot forging, rolling, severe plastic deformation forms, friction extrusion, conform process and etc. [7]. Products by solid-state recycling of aluminum chips in hot extrusion process are controlled by many factors such as die geometry, extrusion ratio, temperature related parameters and etc. in which each of them could influence the extrudates' quality [8,9]. This study investigates the effects of preheating temperature and preheating time on the response variables. In engineering applications, upgrading the mechanical and physical properties of the material is necessary. Upgrading necessitates the use of a suitable heat treatment process to improve the tensile strength and microhardness.

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2. Experimental Procedure

Chips preparing was by comminuting the aluminum block through high-speed milling. Selection of the milling type was because of their having a thinner shape which can result in better deformability [10]. The sizes of the chip particles were examined by a Toolmaker measuring microscope equipped with a digital Nikon MM-60 camera where machined chips with the average dimensions of 3.10 - 3.20 mm length × 1.097 mm width × 0.091 mm thickness with 24.43 surface area of AA6061. The chips were degreased with acetone inside an ultrasonic bath for ten minutes for vanishing any dirt and impurities. The cleaning of the chips method followed ASTM G131-96, the standard practice applicable to clean materials by ultrasonic methods. The total surface area of the machined chips was estimated using to assume that the produced chips followed a cubical shape. The cleaned machining chips were then put in a cylindrical container and compacted at room temperature by a cold press for forming billets of size 30 mm in diameter and height of approximately 80 mm. The sequence of the chip preprocessing to product the billet is shown in Fig. 1. The billets were extruded through the designated conditions as shown in Table 1. The ranges of temperature and preheating time selected were between 450 and 550 °C and 1 and 3 hr, respectively. The maximum temperature was limited to 550 °C because heating the billet above 550 °C leads to hot cracks in the surface of the extrudates, while the ram speed setting was limited to below or equal to 1mm/s to prevent an in homogeneous material flow due to the effect stick-slip resulting in chatter marks on the profile surface at a higher speed [11]. The heat was generated using a ceramic heater installed around the container. A graphite-based lubricant was used over the inner surface of the container and the die at every cycle of extrusion in order to forbid the increase in extrusion load as an effect of friction.

The tensile tests of specimens were fabricated following the ASTM- E8 M and carried out at an initial strain rate of 2.5 × 10−3 s−1 at room temperature on a Testometric™ M500 100 kN tensile test machine and pulled to failure. Microhardness tests were fulfilled by an applied load of 0.9807 N and a holding time of 10 s at room temperature, according to the DIN EN ISO 6507-1:2005 standard. Different points were considered to look out the uniformity of the weld region during the microhardness measurement. The values of microhardness are taken as an average of three plane measurements (top, center, and bottom).

Fig. 1 - Preprocessing of chips before consolidation

Table 1 - Parameter setting of hot extrusion process

Parameter	Value/type
Extrusion die	Round
Extrusion ratio R	5.4
Billet ϕ (mm)	30
Extrusion speed (mm/s)	1
Container temp (°C)	300
Die temp. (°C)	300
Preheating temp. (°C)	450,500,550
Preheating time (hr)	1,2,3

2.1 Classification of the Specimens

Experimental runs based on the 22 full factorial design was performed to investigate the effects of two process parameters as aforementioned. Three center points were included in the design to check the curvature effect of the model and the interactions between parameters were also considered. The design scheme is listed in Table 2. Only single run was implemented in each corner and total 11 runs were involved. The details of the experimental run are given in Table 3. Responses in this study were tensile strength and microhardness of the fabricated samples. Analysis

of variance (ANOVA) was applied to rank the main effects and to analyse the interactions between the input parameters. The DOE results can suggest an insight of further experimental direction for process optimization, then the heat treatment process is carried out for the optimization case and compared to as-received alloy and non-treated recycled cases.

Table 2 - Design scheme of process parameters and their levels

Parameter symbol	Parameter	Level		
		Low (-1)	Center (0)	High (+1)
A	Preheating temperature (°C)	450	500	550
B	Preheating	1	2	3

2.2 Heat Treatment Process

Heat treatment of aluminum was a heat-treating process in which aluminum was exposed to an elevated temperature for a period of time and then cooled off. This process transforms or changes the mechanical properties without changing the specimen shape. Heat treatment can be defined as an operation or set of operations in a metal involving in heating and controlled cooling. Transformation in the solid state can be obtained by the heat-treatment process, which causes changes in microstructure images in materials with a wide range of hardness and mechanical properties [12-14]. Two steps were performed in heat treatment process: quenching and artificial aging. The quenching process was held at 530 °C for 2 h soaking time, followed by quenching in water to reach room temperature. The aging process was conducted at 175 °C for 4 hrs, followed by air cooling at room temperature. Fig. 2 shows the profiles of quenching and the aging process. Heat treatment was performed in the furnace as shown in Fig. 3.

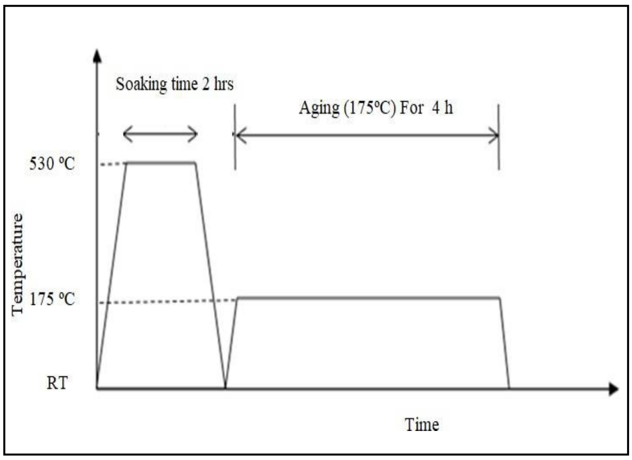


Fig. 2 - Profiles of quenching and the aging process

Fig. 3 - Furnace for heat treatment

3. Results and Discussion

Total eleven runs were carried out according to the full factorial design with three center points. The overall results of the experiments are presented in Table 3. The data shows that the maximum preheating temperature gives the high resulting tensile strength while the high microhardness was gained from the minimum preheating temperature. The discussion is carried out by assisting the explanation on ANOVA of the DOE, similar to that commented by Shamsudin [15] in his research findings.

3.1 Analysis of ANOVA Results

The ANOVA result indicates that the significant term contributing to tensile strength and microhardness in direct hot extrusion of aluminium alloy AA6061 is preheating temperature, it indicated by $p < 0.05$ as shown in Table 4 and 5 and Pareto Chart as shown in Fig.4 - (a)(b) for both responses. The remaining factors, preheating time and interaction of preheating temperature and preheating time are not significant.

The samples are at the lowest temperature showed low tensile strength and conversely. The temperature brought a profound effect on strengthening the chips. Increasing the temperature to 550°C improves solely the tensile strength. Furthermore, the worst performance in terms of strength can be observed in all the samples extruded at 450 °C. The results inferred that the extrusion process at a low billet temperature could not efficiently consolidate materials. The above findings were similar to those commented by Shamsudin and Lela [8,16].

Table 3 - Data of tensile strength results

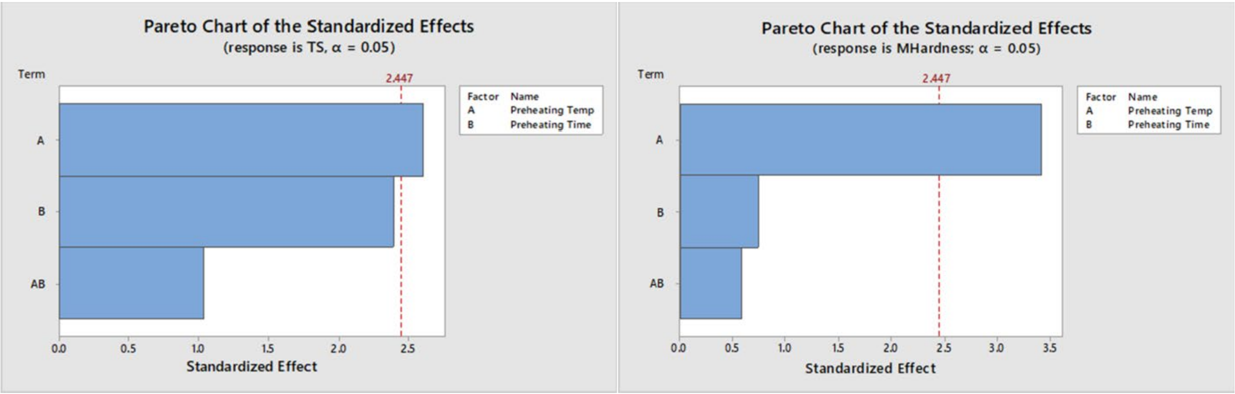
Sample Designation	Std. Order	Preheating Temperature (A) (°C)	Preheating Time(B) (hr)	Tensile Strength (TS) (MPa)	Microhardness (MH)
S1	1	450	1	126.370	50.9254
S2	2	550	1	144.088	44.9448
S3	3	450	3	143.323	49.9987
S4	4	550	3	147.717	44.2872
S5	5	450	1	73.378	55.6886
S6	6	550	1	145.000	44.3944
S7	7	450	3	140.471	50.9192
S8	8	550	3	174.620	44.3572
S9	9	500	2	160.023	44.8555
S10	10	500	2	164.056	42.2784
S11	11	500	2	156.544	51.4043

Table 4 - Analysis of ANOVA of Tensile Strength

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	4	5274.8	1318.7	4.40	0.053
Linear	2	3764.0	1882.0	6.28	0.034
Preheating Temp	1	2044.3	2044.3	6.82	0.040
Preheating Time	1	1719.8	1719.8	5.74	0.054
2-Way Interactions	1	322.5	332.5	1.08	0.340
Preheating Temp *Preheating Time	1	322.5	322.5	1.08	0.340
Curvature	1	1188.2	1188.2	3.96	0.094

Table 5 - Analysis of ANOVA of Microhardness

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	4	126.185	31.546	3.37	0.090
Linear	2	114.243	57.122	6.10	0.036
Preheating Temp	1	109.138	109.138	11.65	0.014
Preheating Time	1	5.105	5.105	0.55	0.488
2-Way Interactions	1	3.127	3.127	0.33	0.584
Curvature	1	8.815	8.815	0.94	0.369



(a) (b)

Fig. 4 - Pareto Chart of (a) Tensile strength; (b) Microhardness

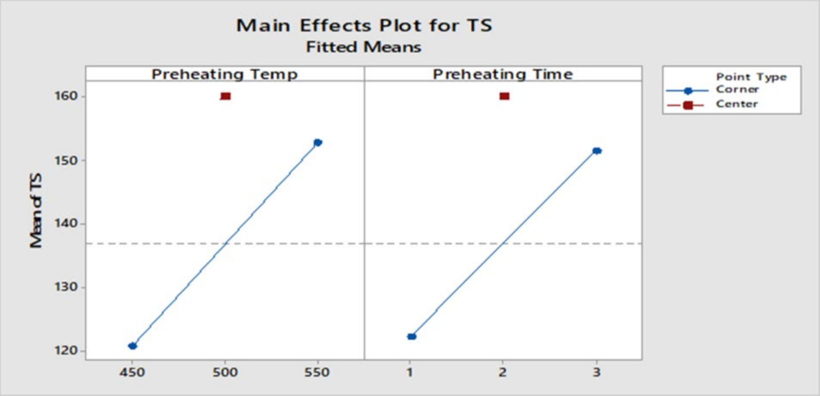


Fig. 5 - Main effects plot for TS

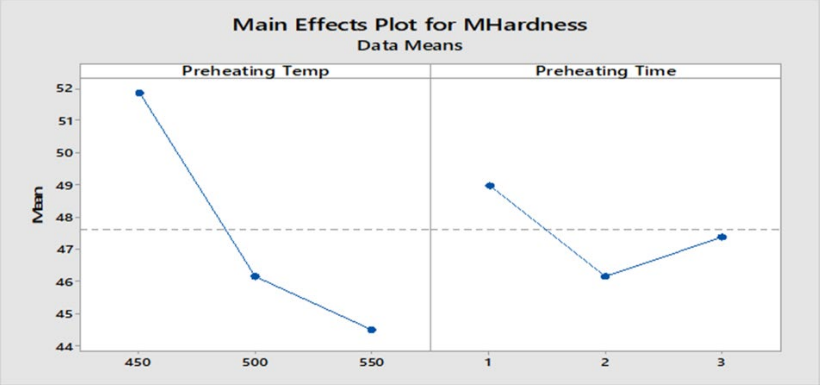


Fig. 6 - Main effect plot for microhardness

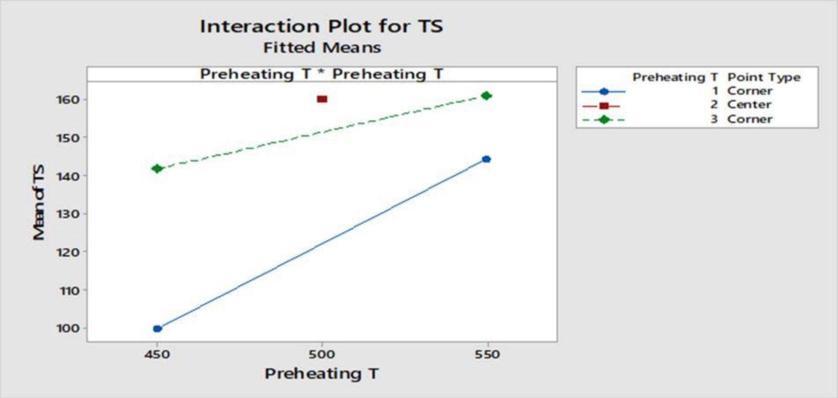


Fig. 7 - Interaction Plot for TS

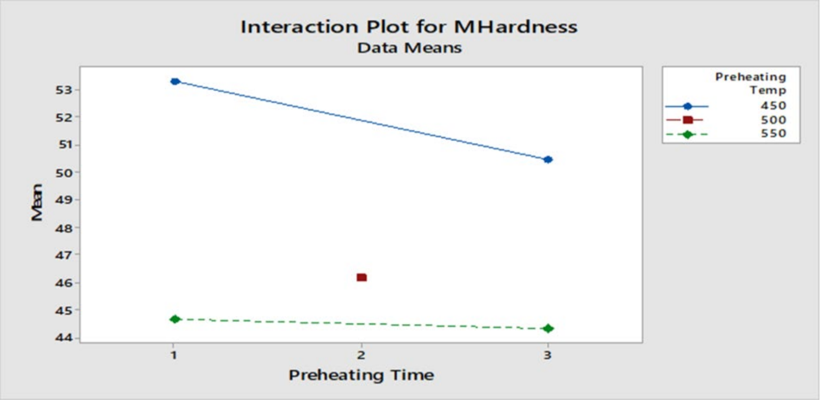


Fig. 8 - Interaction Plot for microhardness

The microhardness is sensitive to the extrusion preheating temperature because extruded samples at lower preheating temperature are found to initiate that amount of normal stress and shear strain at the zone neighboring to the die wall are affective factors to form a hard skin on surfaces of extrudes. Because of hard skin layer, the plastic flow of the chips is limited to a generally small region underneath the indenter to bring about higher hardness. In DOE analysis the main effects plot as shown in Fig. 5 and Fig. 6 clearly shows that all the center points are quite close to the lines connected the average tensile strength and microhardness respectively of all parameters. As can be seen in interaction plot as given in Fig. 7 and Fig. 8, they depict the same trend. They show that the final model selected is appropriate for the observed data. On the other hand, the curvature effect is insignificant on the responses and also confirmed by the ANOVA results in Tables 4 and 5, where $p > 0.05$ for the curvature term of the two responses. Therefore, linear model is enough to fit all the data of the responses.

3.2 Heat treatment results

The heat-treatment process was applied to the prepared material. The alloying constituents are taken into the solution and retained by rapid quenching. Subsequently, artificial aging was performed at low temperatures. The aging process was allowed for a controlled precipitation of the constituents. As such, the strength and microhardness increased. Heat treatment was carried out to optimum specimen. Fig. 9 illustrates the relationship between the type of specimen and the responses.

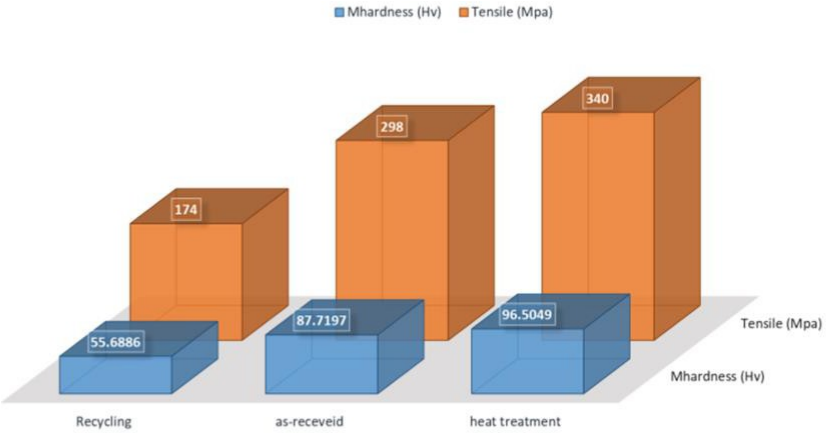


Fig. 9 - The type of specimens against ultimate tensile strength and microhardness

It can be seen that the ultimate tensile strength of the specimen as received for the material AA6061 was 298 MPa, while was 174 MPa for the specimen as fabricated with the optimum condition of hot extrusion process. For microhardness, it was 87.7 HV of as received material and 55.86 HV of the recycled material for the optimum case. The improvement values of ultimate tensile strength and microhardness were gotten when the heat treatment process was done. The improvement ratio was 14% of the received material and 95% of the recycled material for the tensile strength while was 10% of the received material and 73.5% of the recycled material for microhardness. The ultimate tensile strength and microhardness of specimens were extruded with optimum conditions of the process followed by heat treatment was 340 MPa. and 96.5 HV.

Fig. 10 shows the microstructure for the used specimens. It also can be seen, although the extrusion conditions were optimum compare with others, some cracks were appeared. These cracks were caused to reduce the ultimate tensile strength and microhardness. Furthermore, the grain size was tested; it is bigger than the grain size in received material. It was 35 µm while it was 25 µm at received material. Basically, if the grain size was bigger, the mechanical properties were smaller. On the other hand, the extruded specimen with the optimum condition followed by heat treatment was gotten on the higher value of ultimate tensile strength and microhardness. These results were attributed to the smaller size of grain size and the created compounds ($Cr_{23}Ni_5Si_2$, $Al_{86}Fe_{24}$) during heat treatment process as shown in Fig. 11.

4. Conclusion

According to experimental, it is revealed that the hot extrusion process and heat treatment process were successfully conducted. So, it can be concluded that the effect of heat treatment on the responses were showed. By the results, the improvement ratio was 14% of the received material and 95% of the recycled material for the tensile strength while was 10% of the received material and 73.5% of the recycled material for microhardness. The increasing of the two responses was attributed to the created compounds ($Cr_{23}Ni_5Si_2$, $Al_{86}Fe_{24}$).

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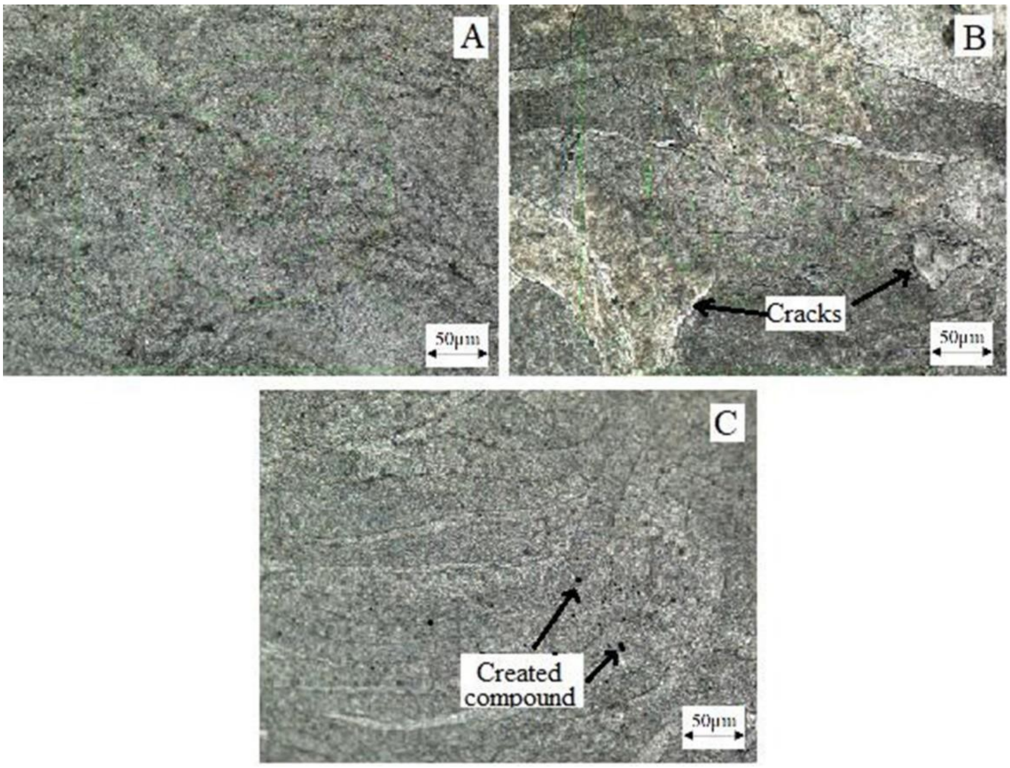

Fig. 10 - Microstructure for the used specimens of (a) as receive specimen; (b) extruded specimen according to optimum condition; (c) extruded specimen followed with heat treatment

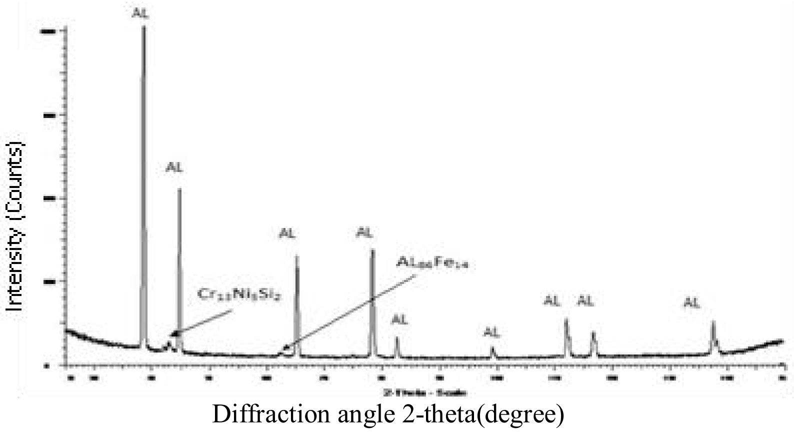

Fig. 11 - XRD of extruded specimen followed with heat treatment

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