Investigation of Chemical Composition on Widely Used Al 6061-T6511 Engineered Material: An XRD Analysis Towards Improvement of Mechanical Properties

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***Abstract*— Al 6061-T6511 alloy is widely used for commercial applications in the transportation, construction and similar engineering industries. It possesses excellent mechanical properties which allow it to be machined rapidly and economically. In addition to that, Al 6061-T6511 also has good corrosion resistance due to which the alloy finds extensive application in operating conditions where such properties are key essentials such as naval vessels manufacturing. This work will utilize X-ray diffraction analysis to provide aid to look into the properties of the alloy, its chemical compound and alloying elements analysis to determine its benefits.**

***Index Terms*— X-ray Diffraction Analysis, Al 6061-T6511, Chemical Composition 1, Introduction, TiAlN Coated Milling tool**

I. Introduction

THIS study makes use of heat treated aluminum alloy as the main work more accurately ALCOA 6061-T6511. Al 6061-T6511 is a solution heat treated alloy which undergoes precipitation hardening to improve its mechanical properties and is considered as one of the most versatile alloy in the Al 6000 series. Precipitation hardening, also called age hardening, is a heat treatment technique used to increase the yield strength of malleable materials, including most popular structural alloys of aluminium, magnesium, nickel and titanium.

It relies on changes in solid solubility with temperature to produce fine particles of an impurity phase, which impede the movement of dislocations, or defects in a crystal's lattice [1]. Since dislocations are often the dominant carriers of plasticity, this serves to harden the material. The impurities play the same role as the particle substances in particle-reinforced composite materials. XRD analysis has also been found useful in the analysis of Portland cement phases coupled with the Rietveld method [3]. Unlike ordinary tempering, alloys must be kept at elevated temperature for hours to allow precipitation to take place. Just as the formation of ice in air can produce clouds, snow, or hail, depending upon the thermal history of a given portion of the atmosphere, precipitation in solids can produce many different sizes of particles, which have radically different properties. Unlike ordinary tempering, alloys must be kept at elevated temperature for hours to allow precipitation to take place [4].

Typical Al 6061 alloys are held in a time delay for the alloying elements and aluminium to fully meld for about 8 hours to a day before undergoing rapid quenching. This time delay is called aging. Al 6061 is widely used in numerous engineering applications including transport and construction where, superior mechanical properties such as tensile strength and hardness are essentially required. Typical mechanical properties for Al 6061 are presented in Table 1. Alloys T6 and T6511 has the highest hardness and tensile strength value amongst all the alloy tempers which makes it highly versatile when high strength and hardness are required in most lightweight fabrications. This is probably due to the amounts of alloying elements contained in the alloy. Most heat treated alloys contain fairly high percentages of alloying elements such as copper, silicon, magnesium, and zinc.

In the case of Al T6 and Al T6511 alloys, they contain approximately 0.40% to 0.8% wt. of Si which contributes to the increase of overall hardness and tensile strength. They can be machined to a good finish with or without cutting fluid, but, in some cases, specially formulated cutting fluid is recommended to obtain optimal or near best surface finish. Machinability groupings for aluminum alloys are useful in specifying tool forms. For the reason, in general metallurgical terms, alloys are classified into five groups; A, B, C, D, and E. However, due to the extensive augmentations to the micro constituents made to alloys, E group is not necessary. From Table 2, Al 6061-T6511 is determined to have a machinability rating of C with close approximation to a B rating. Machinability rating of C implies that the material produces

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continuous chips and a good finish [1]. From the data of Al 6061-T6511 stated above, this work utilizes X-ray diffraction to analyze the chemical composition of Al 6061-T6511 based on the diffraction produced by traces of major alloying constituents, Si & Mn5 and minor micro-constituents, Mg, Ti, & Co2. Previous XRD analysis done on the basic Al 6061 alloy indicated that a high amount of Ti existent in the alloy matrix compound [5]. Fig. 1 show the Al 6061-T6511 alloy specimen.

Table 1: Alloy 6061 Mechanical Property Limits for Various Shapes, [2]

Alloy 6061 Mechanical Property Limits for Rod, Bar, Tube, Pipe and Standard Shapes

Temper	Specified Section or Wall Thickness[2] (inches)	Tensile Strength (ksi) Ultimate Min.	Tensile Strength (ksi) Ultimate Max.	Tensile Strength (ksi) Yield (0.2% offset) Min.	Tensile Strength (ksi) Yield (0.2% offset) Max.	Elongation[3] Percent Min. in 2 inch or 4D[5]	Typical Brinell Hardness (500 kg load/ 10 mm ball)	Typical Ultimate Shearing Strength (ksi)
Standard Tempers[1]								
O	All	—	22.0	—	16.0	16	30	12
T1	Up thru 0.625	26.0	—	14.0	—	16	—	—
T4, T4511[4]	All	26.0	—	16.0	—	16	65	24
T51	Up thru 0.625	35.0	—	30.0	—	8	—	—
T6, T6511[4]	Up thru 0.249	38.0	—	35.0	—	8	95	30
	0.250 and over	38.0	—	35.0	—	10	95	30

Table 2: Comparative Characteristics of Al 6000 Series, [2]

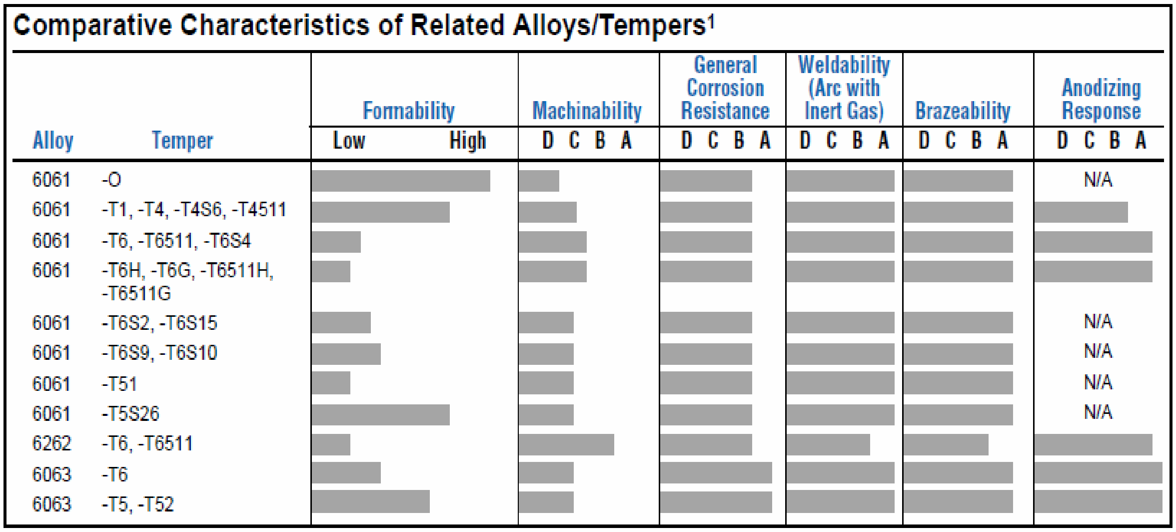

Fig. 1: Al 6061-T6511 alloy specimen prepared for XRD Analysis.

II. Experimental Procedure

XRD is the most direct and accurate analytical method for determining the presence and absolute amounts of mineral species in a sample. Ambiguous results may be obtained however, if the sample chemistry and/or origin are unknown. The purpose of carrying out this study is to locate traces of Silicone (Si) and Manganese (Mn) in the sample.

Also to gauge the amount of Si and Mn present in 6061-T6511 alloy by the analysis of the reflectometry. Distinguishing the presence of these elements in the alloy is imperative because alloys with above 10% wt. of Si have been found to have poor surface finish and traces of Mn have been found to increase ductility in alloys, thus increasing its machinability [2].

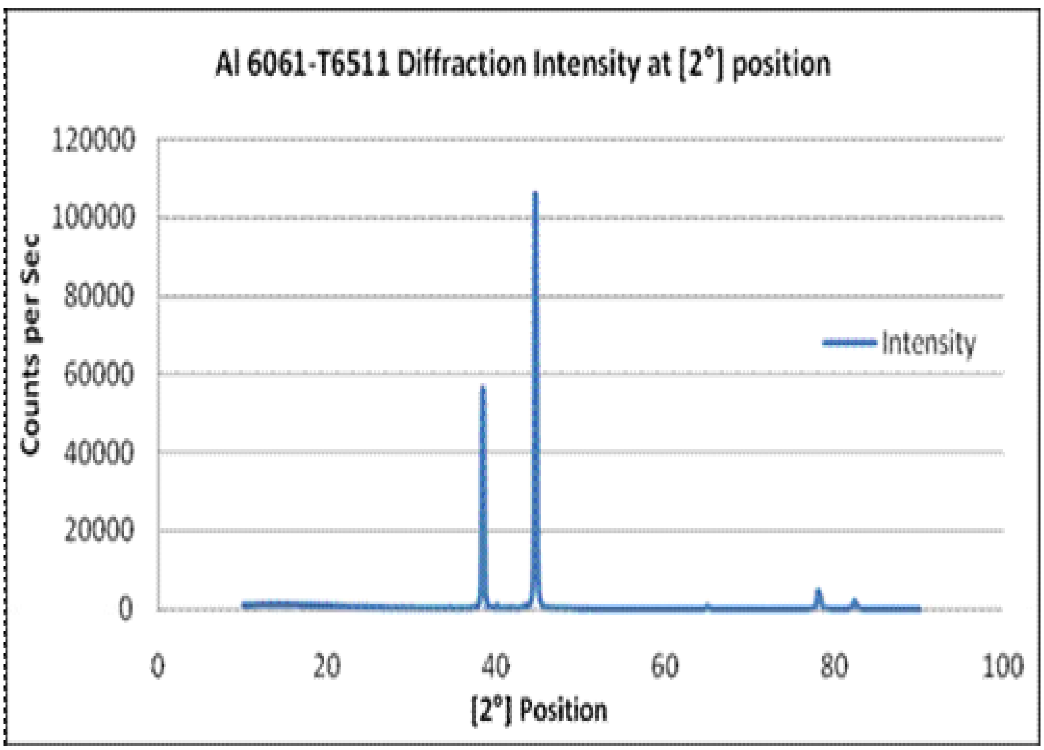

Fig. 2: Graph of Height (counts per sec) vs Angle at room temperature (25°C)

A sample of the alloy measuring 3 × 10.2 mm is taken with a thickness of 1.2 mm for the XRD analysis. This dimension specimen was specially selected so that it would safely be mounted onto the 2 x 2 inch glass holder, where, only specimens that can fit into the holder but large enough to produce a good result should be used is recommended by the XRD machine manufacturer. This specimen was analyzed at the temperature of 25°C at 40kV and 30mA using a Cu anode. It is imperative here not to exceed 40kV and 30mA as this will impede or compromise the results of the analysis. The computer software X'pert Data automatically calculates the appropriate time needed for the scan, and a continuous scan type will be used for this work. Diffraction analysis is done at 25°C with a copper anode at offset [2°Theta] of 0.000. Scan time is 40.7022s with a Start Position [°2Th.] at 10.0114° and an End Position [°2Th.] at 89.9794 with a Step Size of 0.0170.

Fig. 2 illustrates the intensity graph with number of counts versus position [2°Theta] for the carried out experimentation.

III. Results and Discussion

Detailed representation of the diffraction analysis position at which the highest diffraction intensity occurs for Si and Mn5 [2°Theta] position of 44.5612 is shown in Fig. 3. The X-ray diffraction pattern of the alloy presence in the specimen shows that, the diffraction intensity of the alloy is very obvious and mostly consists of Aluminum in addition to traces of Ti, Co2, Si, Si2 and Mn5. The presence of Co2 is mainly due to the use of Co2 as a detriment against wear in alloys such as sliding wear and abrasive wear. Co2 also gives the alloy the metallic shine that always preferred by end users as the esthetic or decorative values.

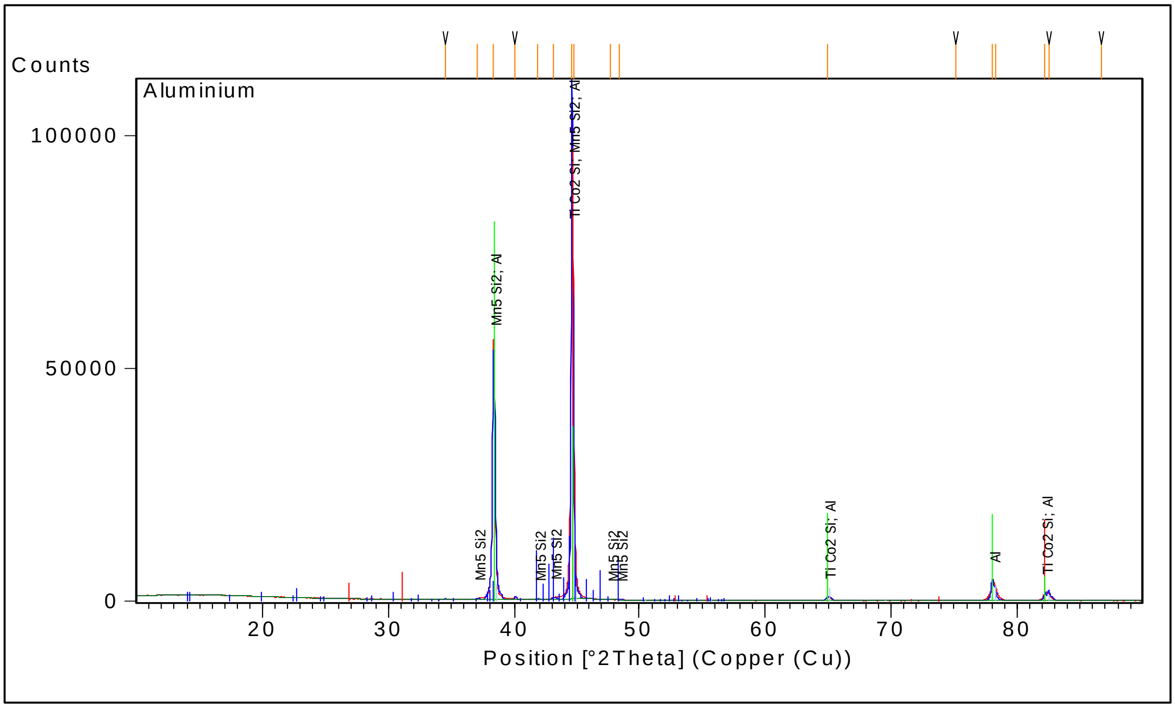

Fig. 3: Elements found in diffraction positions.

Detecting the high level presence of Mn5 although at a low score rating (see Table 3) indicates that the manganese was added to the micro constituents to ease with chip breakage also to impede the sliding of the crystal's lattice. Mn5 is also used to treat alloys to make it more corrosion resistant. Based on the score rating of the XRD analysis, Mn5 is the least element in the alloy (see Table 4). However, aluminum alloys with a Mn5 content of roughly 1.5% has an increased resistance against corrosion due to the formation of grains absorbing impurities which would lead to galvanic corrosion. Si and Si2 found to have a score rating of 22 (see Table 4) which is not unusual in alloys as Si is used mainly as an alloying element. However according to [6], alloys containing more than 10% Si are the most difficult to machine because hard particles of free silicon which leads rapid tool wear. Alloys containing more than 5% Si will not be finished to the bright machined surfaces of other high-strength aluminum alloys, but will have slightly gray surfaces with little luster [7]. The score rating of 8 and scale factor of 0.120 of Si and Mn5 suggests that the alloy contains almost equal amounts of these elements. XRD analysis have also been used in previous work to detect traces of Cu-Co in solid masses [8].

A high amount of Mn5 is seen to be added as a corrosion deterrent agent making the alloy more corrosion proof. A low score rating of 8 between Si and Mn5 is obtained suggesting that Mn5 is at least at an equal percentage to the amount of Si in the sample, with the element indicated on top to be slightly more in weight percentage. However, according to XRD analysis (see Table 4) Si has been found to have a high score rating compared to other elements (Ref. Code: 03-065-5104) thus, with difference of a low score rating of 8 when compared to Mn5 (Ref. Code: 00-030-0826), which indicates that, Mn5 is almost in the same amount of Si in the alloy. This high score rating indicates that the alloy has a high concentration of Si micro-constituents present which would impede smooth sliding of the crystal lattice when the material is under shear or cutting forces making it harder to be machined. Although the amount of Si presence in the alloy does not dictate that it is unmachinable, but it does lower the machinability rating as discussed in the previous section.

Table 3: Position [2° Theta] Height Count

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing [Å]	Rel. Int. [%]
34.5014	209.99	0.1338	2.59966	0.20
37.0921	307.16	0.2007	2.42382	0.30
38.3366	55006.02	0.2175	2.34796	53.03
40.0563	783.02	0.1171	2.25103	0.75
41.8185	112.44	0.3346	2.16016	0.11
43.1039	449.72	0.2676	2.09867	0.43
44.5612	103726.20	0.1224	2.03169	100.00
44.6936	67129.77	0.0816	2.03101	64.72
47.7427	69.93	0.2448	1.90345	0.07
48.4138	121.81	0.2448	1.87863	0.12
64.9569	712.77	0.3672	1.43450	0.69
75.1776	24.57	0.9792	1.26281	0.02
78.0318	4334.88	0.2244	1.22360	4.18
78.2725	3136.13	0.1632	1.22347	3.02
82.2027	1666.67	0.1836	1.17175	1.61
82.5220	1391.21	0.2040	1.16802	1.34
86.6866	36.06	0.4896	1.12228	0.03

Table 4: Score Rating for Different Compounds in Al 6061-T6511

Visible	Ref. Code	Score	Compound Name	Displacement [°2Th.]	Scale Factor	Chemical Formula
*	03-065-5104	22	Silicon Cobalt Titanium	0.000	0.861	Ti Co2 Si
*	00-030-0826	8	Manganese Silicon	0.000	0.120	Mn5 Si2
*	01-089-2837	26	Aluminum	0.000	0.723	Al

IV. CONCLUSION

The outcome of the research can be drawn as below:

- XRD analysis indicates that Al 6061-T6511 to contain high score rating of Si when compared to traces of Co2 and Ti.
- The score rating from the XRD analysis revealed that the alloy contained approximately the same amount Si and Mn5 (Ref code: 00-030-0826) with a slightly higher presence of Mn5 to Si comparatively.
- High amounts of Mn5 obtained from the XRD analysis shows that the Al 6061-T6511 has high corrosion resistance and good ductility.
- XRD could only indicate elements present in an alloy relative to others around micro constituents, on the other hand, XRF can accurately quantify the elements in the alloy.

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