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OPTIMIZATION OF THE TURNING PARAMETERS IN MACHINING OF AA6061-AlN COMPOSITES

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Abstract : Aluminum composites have gained a lot of interest in the material manufacturing world replacing the applications of ferrous materials. It is widely used in aerospace, space craft, and army and navy applications as it is moderate strength and less weight material. It is three times less in weight when compared to ferrous materials. The density of aluminum alloy is 2.7g/cm3 whereas a ferrous material has 7.87g/cm3. Also compared to iron the Aluminum composite has good corrosion resistant properties making it the most suitable for the replacement to ferrous materials. Optimizing the machinability parameters is essential to maintain accuracy of the components and obtain the cost effectiveness. The main parameters in machining process are feed rate, depth of cut and speed. Cutting force, surface roughness and tool wear are considered as important response to control dimensional accuracy of the components. The main objective of the project is to optimize the machining parameters to minimize cutting force, flank wear and surface roughness in turning of AA6061-AlN composite material with various reinforcement ratios. Experimentation was conducted by using L27 layout. Taguchi method is applied to optimize the machining parameters. Analysis of the result shows that the feed rate has strongest effect on cutting forces and surface roughness whereas reinforcement ratio has strongest effect on flank wear.

***Keywords* - Turning, wear, cutting force, AlN composites, optimization.**

I. INTRODUCTION

There is a great need for materials with special properties with emergence of new technologies. However, conventional engineering materials are unable to meet this requirement of special properties like high strength and low-density materials for aircraft applications. Thus, emerged new class of engineering materials composites. Unfortunately, there is no widely accepted definition for a composite material. For the purpose of this module, the following definition is adopted: any multi phase material that is artificially made and exhibits a significant proportion of the properties of the constituent phases. The constituent phases of a composite are usually of macro sized portions, differ in form and chemical composition and essentially insoluble in each other. Composites are, thus, made by combining two distinct engineering materials in most cases; one is called matrix that is continuous and surrounds the other phase – dispersed phase. The properties of composites are a function of the properties of the constituent phases, their relative amounts, and size-and-shape of dispersed phase. Millions of combinations of materials are possible and thus so number of composite materials. For ease of recognition, it is understandable that properties of composite materials are nothing but improved version of properties of matrix materials due to presence of dispersed phase. However, engineers need to understand the mechanics involved in achieving the better properties. Hence the following sections highlight the mechanics of composites, which depend on size-and shape of dispersed phase.

Generally, a composite material is composed of reinforcement (fibres, particles, flakes, and/or fillers) embedded in a matrix (polymers, metals, or ceramics). The matrix holds the reinforcement to form the desired shape while the reinforcement improves the overall mechanical properties of the matrix. When designed properly, the new combined material exhibits better strength than would each individual material.

1.1 Composite

The biggest advantage of modern composite materials is that they are light as well as strong. By choosing an appropriate combination of matrix and reinforcement material, a new material can be made that exactly meets the requirements of a particular application. Composites also provide design flexibility because many of them can be moulded into complex shapes. The down side is often the cost. Although the resulting product is more efficient, the raw materials are often expensive.

While composites have already proven their worth as weight-saving materials, the current challenge is to make them cost effective. The efforts to produce economically attractive composite components have resulted in several innovative manufacturing techniques currently being used in the composites industry. It is obvious, especially for composites, that the improvement in manufacturing technology alone is not enough to overcome the cost hurdle. It is essential that there be an integrated effort in design, material, process, tooling, quality assurance, manufacturing, and even program management for composites to become competitive with metals. These composites are used in Aerospace engineering, Automotive engineering Bath tubes and shower stalls, Fiberglass doors, Composite decking, Window frames, Hot tubs and spas, Ballistic protection, Boating, Sports.

1.2 Reinforcement

The reinforcement material is embedded into a matrix. The reinforcement does not always serve a purely structural task (reinforcing the compound) but is also used to change physical properties such as wear resistance, friction coefficient, or thermal conductivity. The reinforcement can be either continuous, or discontinuous. Discontinuous MMCs can be isotropic, and can be worked with standard metal working techniques, such as extrusion, forging, or rolling. In addition, they may be machined using conventional techniques, but commonly would need the use of polycrystalline diamond tooling (PCD).

Continuous reinforcement uses monofilament wires or fibres such as carbon fibre or silicon. Because the fibres are embedded into the matrix in a certain direction, the result is an anisotropic structure in which the alignment of the material affects its strength. One of the first MMCs used boron filament as reinforcement. Discontinuous reinforcement uses "whiskers", short fibres, or particles. The most common reinforcing materials in this category are alumina and silicon carbide.

1.3 Turning

Turning is a machining process in which a cutting tool, typically a non-rotary tool bit, describes a helix tool path by moving more or less linearly while the work piece rotates. The tool's axes of movement may be literally a straight line, or they may be along some set of curves or angles, but they are essentially linear (in the non-mathematical sense). Usually the term "turning" is reserved for the generation of external surfaces by this cutting action, whereas this same essential cutting action when applied to internal surfaces (that is, holes, of one kind or another) is called "boring". Thus, the phrase "turning and boring" categorizes the larger family of (essentially similar) processes known as lathing. The cutting of faces on the work piece (that is, surfaces perpendicular to its rotating axis), whether with a turning or boring tool, is called "facing", and may be lumped into either category as a subset.

When turning, a piece of relatively rigid material (such as wood, metal, plastic, or stone) is rotated and a cutting tool is traversed along 1, 2, or 3 axes of motion to produce precise diameters and depths. Turning can be either on the outside of the cylinder or on the inside (also known as boring) to produce tubular components to various geometries. Although now quite rare, early lathes could even be used to produce complex geometric Figs.

The turning processes are typically carried out on a lathe, considered to be the oldest machine tools, and can be of four different types such as straight turning, taper turning, profiling or external grooving. Those types of turning processes can produce various shapes of materials such as straight, conical, curved, or grooved work piece. In general, turning uses simple single-point cutting tools. Each group of work piece materials has an optimum set of tools angles which have been developed through the years.

1.4 Surface Roughness Tester

Surface roughness testers are common instruments used on the shop floor. A diamond stylus is traversed across the specimen and a piezo electric pickup records all vertical movement. Peaks and valleys are recorded and converted into a known value of a given parameter. Parameters differ in how they approach looking at peaks and valleys. The most popular parameter is “Ra”. Ra is commonly defined as the arithmetic average roughness. While the Ra parameter is easy and efficient, there are other parameters that can be more specific and useful depending on the application requirements. It is the parameters that enable us to define surface roughness. Today, for the purpose of checking Ra values, the use of portable, hand held, surface roughness testers are not only economical, but are digital and easy to use. These surface roughness testers are a given necessity for any shop floor that receives work with Ra requirements

Equations

The design of experiments using the orthogonal array is the efficient in comparison to many other statistical designs. The minimum number of experiments that are required to conduct is decided by the Taguchi method which can be calculated based on the degrees of freedom approach (Eq.3.1).

$$N_{\text{Taguchi}} = 1+\sum_{i=1}^{f}(L_i - 1)$$

Where N_{Taguchi}= Minimum number of experiments to be conducted in Taguchi method.
f = Number of parameters;
L = Levels of each parameter

II. RESEARCH METHODOLOGY

The methods that have been used for conducting the study and for the data used in this study. It describes the various optimization methods Taguchi Methodology, Analysis of variance, S/N ratio Analysis.

2.1Design of Experiments

A Design of Experiments (DOE) is the design of any task that aims to describe or explain the variation of information under conditions that are hypothesized to reflect the variation. The term is generally associated with experiments in which the design introduces conditions that directly affect the variation but may also refer to the design of quasi-experiments, in which natural conditions that influence the variation are selected for observation.

In its simplest form, an experiment aims at predicting the outcome by introducing a change of the preconditions, which is represented by one or more independent variables, also referred to as "input variables" or "predictor variables." The change in one or more independent variables is generally hypothesized to result in a change in one or more dependent variables, also referred to as "output variables" or "response variables." The experimental design may also identify control variables that must be held constant to prevent external factors from affecting the results. Experimental design involves not only the selection of suitable independent, dependent, and control variables, but planning the delivery of the experiment under statistically optimal conditions given the constraints of available resources. There are multiple approaches for determining the set of design points (unique combinations of the settings of the independent variables) to be used in the experiment.

2.2Orthogonal array of L27 layout

In this array represented in table 5.0, the columns are mutually orthogonal. That is for any pair of columns all combination of factors occurs, and they occur on each number of times. Here there are 4 parameters, A, B, and C each at three levels. This is called an ‘L27’ design; with the 27 indications seven rows, configurations or prototypes to be tested. Specific test characteristics for each experimental evaluation are identified in the associated row of the table thus L27 means that twenty-seven experiments are to be carried out to study four variables with three levels. There are greater savings in testing for larger arrays. The following Table 5.0 represents orthogonal array of L27 layout.

2.3Taguchi Methodology for Optimization

In Taguchi Method, the word "optimization" implies "determination of BEST levels of control factors". In turn, the BEST levels of control factors are those that maximize the Signal-to-Noise ratios. The Signal-to-Noise ratios are log functions of desired output characteristics. The experiments, that are conducted to determine the BEST levels, are based on "Orthogonal Arrays", are balanced with respect to all control factors and yet are minimum in number. This in turn implies that the resources (materials and time) required for the experiments are also minimum.

Taguchi method divides all problems into 2 categories - STATIC or DYNAMIC. While the Dynamic problems have a SIGNAL factor, the Static problems do not have any signal factor. In Static problems, the optimization is achieved by using 3 Signal-to-Noise ratios - smaller-the-better, LARGER-THE-BETTER and nominal-the-best. In Dynamic problems, the optimization is achieved by using 2 Signal-to-Noise ratios - Slope and Linearity.

Taguchi Method is a process/product optimization method that is based on 8-steps of planning, conducting and evaluating results of matrix experiments to determine the best levels of control factors. The primary goal is to keep the variance in the output very low even in the presence of noise inputs. Thus, the processes/products are made ROBUST against all variations.

2.4Signal-To-Noise Ratio

S/N ratio is defined as the ratio of signal power to the noise power, often expressed in decibels. A ratio higher than 1:1 (greater than 0 dB) indicates more signal than noise. While SNR is commonly quoted for electrical signals, it can be applied to any form of signal (such as isotope levels in an ice core or biochemical signalling between cells or financial trading signals).

Signal-to-noise ratio is sometimes used metaphorically to refer to the ratio of useful information to false or irrelevant data in a conversation or exchange. For example, in online discussion forums and other online communities, off-topic posts and spam are regarded as "noise" that interferes with the "signal" of appropriate discussion.

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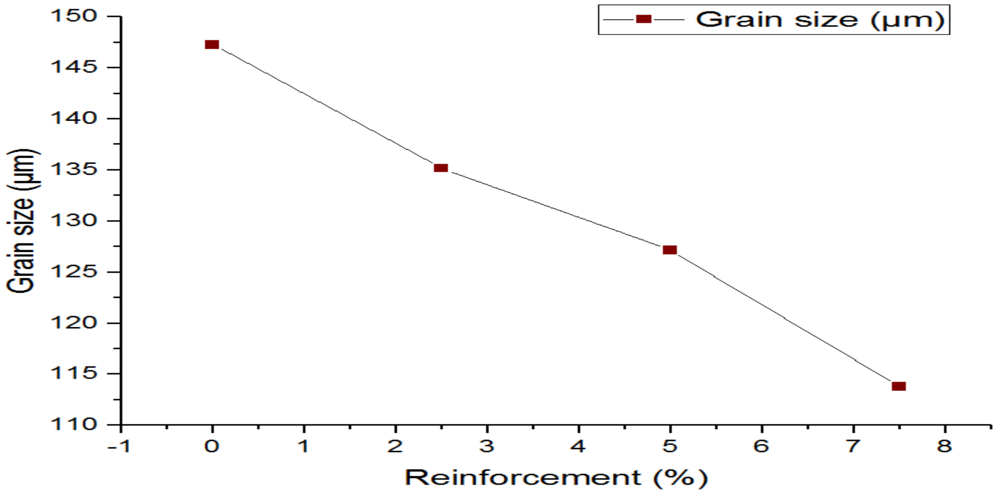
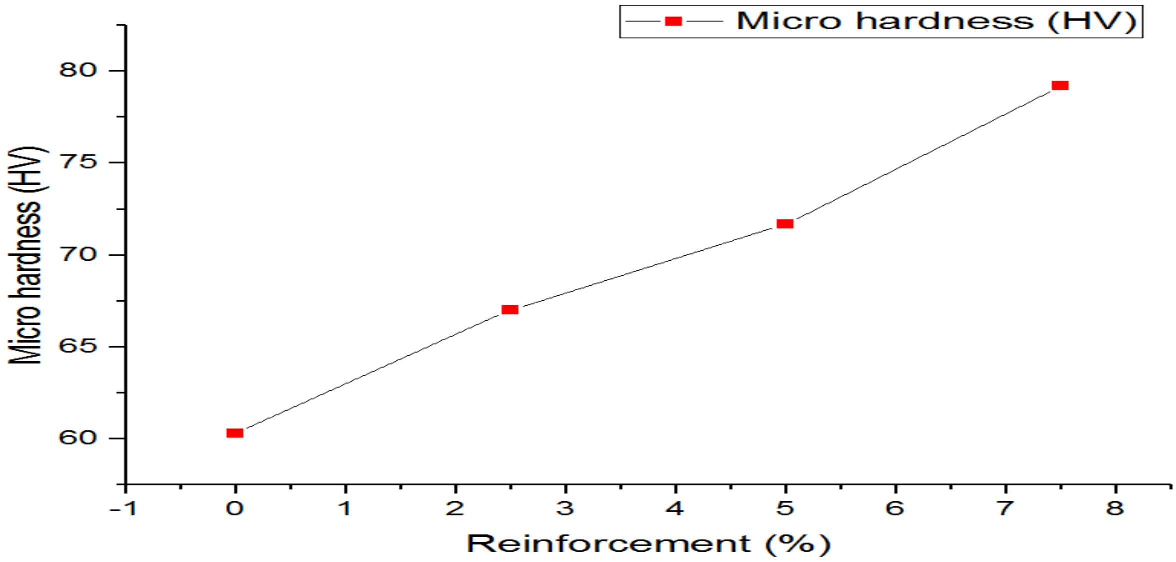
S.no.	Speed (mm/min)	Feed rate (mm/rev)	% AlN
1	50	0.1	2.5
2	50	0.1	5
3	50	0.1	7.5
4	50	0.15	2.5
5	50	0.15	5
6	50	0.15	7.5
7	50	0.2	2.5
8	50	0.2	5
9	50	0.2	7.5
10	75	0.1	2.5
11	75	0.1	5
12	75	0.1	7.5
13	75	0.15	2.5
14	75	0.15	5
15	75	0.15	7.5
16	75	0.2	2.5
17	75	0.2	5
18	75	0.2	7.5
19	100	0.1	2.5
20	100	0.1	5
21	100	0.1	7.5
22	100	0.15	2.5
23	100	0.15	5
24	100	0.15	7.5
25	100	0.2	2.5
26	100	0.2	5
27	100	0.2	7.5

2.5Grain Size



2.6Microhardness



III. RESULTS AND DISCUSSION

3.1 Analysis for Surface Roughness

3.1.1 Means of Means ratios for Surface Roughness:

The Fig 3 above shows the relationship between three different parameters speed, feed, and %Al N with Surface roughness. The following analysis can be made from the above Fig 3.

- The surface roughness is optimal at high speed, low feed rate, and high % of reinforcement,
- The surface roughness decreases up to a minimum point and the increases in speed.
- It is increases with increase in feed rate.
- On high reinforcement ratio the surface roughness is decreases.

3.1.2 Analysis of Variance (ANOVA) for Surface roughness

Source	Degree of freedom	Seq ss	Adj ss	Adj ms	% of contribution
Speed	2	18.6728	18.6728	9.3364	24.56%
Feed Rate	2	50.6152	50.6152	25.3076	66.61%
%Al N	2	5.677	5.677	2.8388	7.47%
Speed vs feed rate	4	0.0944	0.0944	0.0236	0.12%
Speed vs %Al N	4	0.0212	0.0212	0.0053	0.03%
Feed rate vs %Al N	4	0.5765	0.5765	0.1441	0.75%
Resdiual Error	8	0.3293	0.3293	0.0412	0.43%
Total	26	75.9869			100%

From the Table 2, Statistical results illustrates that the speed, feed, % AlN effects the Surface Roughness 24.56%, 66.61% and 7.47% in Centre Lathe machining of AA6061-AlN ex-situ composites respectively. From the above data we can conclude the fact that feed rate has the maximum affect in the case of Surface roughness and %Al N contributes the lowest of all.

3.1.3 Regression Equation for Surface roughness

Surface roughness = 5.3919 + 0.5193 Speed_1 + 0.1537 Speed_2 - 0.6730 Speed_3
- 0.8463 Feed rate_1 - 0.3507 Feed rate_2 + 1.1970 Feed rate_3
- 0.1496 % Aln_1 + 0.3881 % Aln_2 - 0.2385 % Aln_3

3.2 Analysis for Cutting Force

3.2.1 Means of Means ratios for Cutting force

The above Fig 4 shows the relationship between three different parameters speed, feed, and %AlN with cutting force. The following analysis can be made from the above data.

- The cutting force increases with the increases in feed.
- It increases to a maximum range and then decreases in the case of % AlN.
- The cutting force decreases with the increases in speed.
- The optimal values of cutting force is at high speed, low feed rate, and low reinforcement ratio

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3.2.2 Analysis of Variance (ANOVA) for Cutting force

Source	Degree of freedom	Seq ss	Adj ss	Adj ms	% of contribution
Speed	2	179.861	179.861	89.931	29.87%
Feed Rate	2	346.33	346.33	173.165	57.52%
%Al N	2	8.26	8.26	4.130	1.37%
Speed vs feed rate	4	50.058	50.058	12.514	8.31%
Speed vs %Al N	4	4.461	4.461	1.115	0.01%
Feed rate vs %Al N	4	5.128	5.128	1.282	0.85%
Resdiual Error	8	7.97	7.97	0.996	1.32%
Total	26	602.069	602.069		100%

From the Table 4, Statistical results illustrates that the speed, feed, % AlN effects the Cutting force 29.87%, 57.52% and 1.37% in Centre Lathe machining of AA6061-Al N ex-situ composites respectively. From the above data we can conclude the fact that feed rate has the maximum effect in case of Cutting force and %Al N contributes the lowest of all.

3.2.3 Regression Equation for Cutting force

Cutting force = 340.53 + 135.2 Speed_1 - 44.6 Speed_2 - 90.7 Speed_3
- 142.4 Feed rate_1- 27.8 Feed rate_2 + 170.2 Feed rate_3
- 12.7 % Aln_1 + 21.6 % Aln_2- 8.9 % Aln_3

3.3Analysis for Flank Wear

3.3.1 Means of Means ratios for Flank Wear

The above Fig 5. shows the relationship between three different parameters speed, feed, and % AlN with Flank Wear. The following analysis can be made from the above data.

- The flank wear increases to a maximum range and then decreases with the increases in speed.
- It increases with increase in feed rate.
- The flank wear increases with increase in % AlN
- The optimal value of flank wear is obtained at low speed, low feed rate, and low reinforcement ratio.

3.3.2 Analysis of Variance (ANOVA) for Flank wear

Source	Degree of freedom	Seq ss	Adj ss	Adj ms	% of contribution
Speed	2	4.0842	4.0842	2.0451	4.30%
Feed Rate	2	13.8469	13.8469	6.9235	14.58%
%Al N	2	72.3011	72.3011	36.1505	76.12%

Speed vs feed rate	4	0.9276	0.9276	0.2319	0.97%
Speed vs %Al N	4	1.3262	1.3262	0.3315	1.39%
Feed rate vs %Al N	4	0.1694	0.1694	0.0424	0.17%
Resdiual Error	8	2.316	2.316	0.2895	2.43%
Total	26	94.9714			100%

From the Table 5, statistical results illustrate that the speed, feed, % AlN effects the flank wear 4.30%, 14.58% and 76.12% in centre lathe machining of AA6061-AlN ex-situ composites respectively. From the above data we can conclude the fact that reinforcement ratio(% AlN) has the maximum effect in case of flank wear and speed contributes the lowest of all.

3.3.3 Regression equation for flank wear

Flank wear = 0.14453 - 0.00789 Speed_1 + 0.00580 Speed_2 + 0.00210 Speed_3
- 0.01457 Feed rate_1 + 0.00099 Feed rate_2 + 0.01359 Feed rate_3
- 0.03457 % Aln_1 + 0.00913 % Aln_2 + 0.02544 % Aln_3

3.4 SEM Analysis

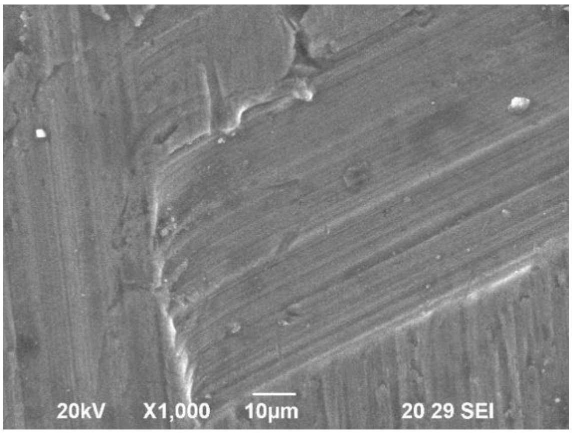

Fig6: 0%AlN

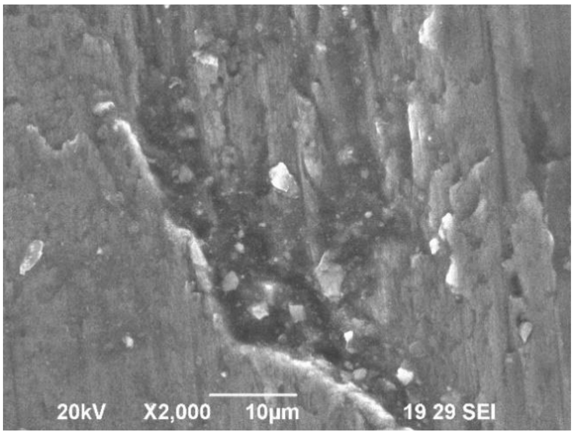

Fig7: 2.5%AlN

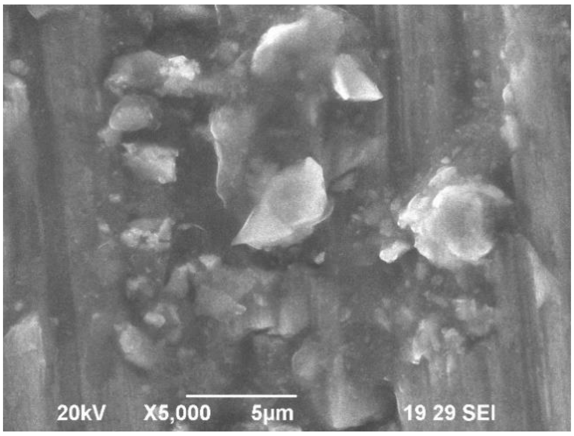

Fig8: 5% AlN

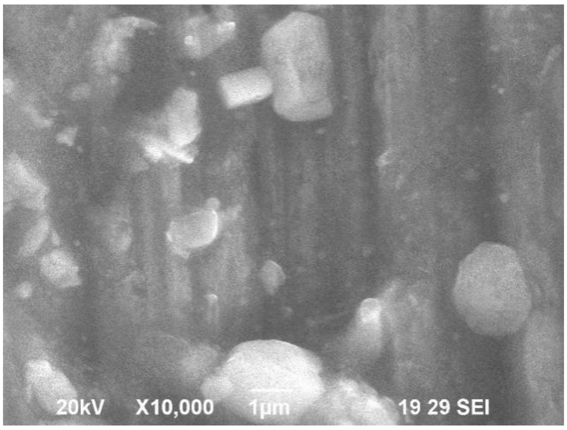

Fig9: 7.5% AlN

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