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Optimization of Process Parameters of Cryogenic Treatment on AL/AL_2O_3 MMCs by Taguchi Method for Tensile Strength.

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ABSTRACT

Engineering materials are given different types of treatment to impart desired properties to the materials to make them suitable for the intended application. The conventional method is heat treatment. It is being followed by many centuries but the treatment of materials below the room temperature is altogether a new concept to enhance the material properties. When the materials are subjected to deep freezing up to -196^{0}C the change in the morphology results in the stability of microstructure & dimensions. Many researchers have proved the usefulness of cryogenic treatment on ferrous materials. But a very little amount of work has been found in the area of nonferrous materials. Taguchi approach was applied to optimize the process parameters of cryogenic treatment on Al6061-Al2O3 MMCs. The results were experimentally validated. It is found that, the Taguchi approach can be used as an effective tool in optimizing the process variables to minimise the laborious effort in conduction of experiments.

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1. Introduction

MMCs are the most promising materials used as advanced materials in space, marine, aerospace and automobile industries due to their enriched properties [1]. The MMCs led to a new generation tailorable engineering materials with improved specific properties the structure and the properties of these composites are controlled by the size & type and of reinforcement and also the bonding nature [2].

Cryo treated MMCs showed very high hardness values, which are due to the formation of ternary phases at the temperatures of consolidation.

This work is aimed at optimization of the cryogenic treatment parameters like temperature and the duration of treatment for varying proportions of reinforcement. The most important robust technique for optimization is Taguchi method [3]. This approach provides a comprehensive understanding of the combined and individual process parameters. The number of simulation trials required will be reduced. This investigation was focused on cryogenic treatment parameters of Metal Matrix Composites considering three levels & three factors each [4].

2. Experimental procedure

The Aluminium 6061 alloy (matrix material) and Al_2O_3 30-50-micron size particles (reinforcement) were used for fabrication of Al6061/Al_2O_3 MMCs. The composition of Al 6061 is given in the Table 1. The reinforcement particle was chosen as commercial Al_2O_3 with 99.5% purity.

Table1: Chemical Composition of Al 6061

Factors	**Control factor**	**DOF**	**Level 1**	**Level 2**	**Level 3**
A	Cryogenic temperature, °C	02	-100	-150	-196
B	Duration of treatment, h	02	0	25	50
C	Wt. % of Al_2O_3	02	0	10	20

3. Design of Experiments (DOE)

The design of experiments is conducted using special matrices called orthogonal arrays, consists of a set of experiments with various process parameters as variables to study from one experiment to another and allows the effect of several parameters to be determined efficiently.

The number of experiments to analyze the factor effects of a process through DOE is denoted by for example; 3^3= 27 experiments, where 3 represents the number of levels and 3 represents the number of factors involved. In general, an experiment in which all-possible combinations of the factor levels are realized is called a full factorial experiment. The numbers of trials in a factorial experiment are considerably high and sometimes impracticable in actual use. In fact, orthogonal array evolved through the concept of fractional replication [5]. In practical scenarios, it is usually tedious and expensive to conduct full factorial experiments. For this reason, orthogonal array method provides techniques where in reducing the full factorial to a fractional factorial which reduces the number of experiments, we can still arrive at the factor effects provided; the layout is such that the factors are kept orthogonal to each other. This outcome eliminates the time and additional costs that are involved in carrying out full factorial experiments [6].

Table 2: Control Parameters of Cryogenic Treatment

Factors	Control factor	D.O.F	Level 1	Level 2	Level 3
A	Cryogenic temperature, °C	02	-100	-150	-196
B	Duration of treatment, h	02	0	25	50
C	Wt. % of Al_2O_3	02	0	10	20

Keeping the parameters of Cryogenic treatment as constants to enable the study of the effect of 1) treatment duration (2) cryogenic temperature and (3) reinforcement wt. %, on the tensile strength of the composite material. The degrees of freedom for three parameters in each of three levels are given in Table 2. The S/N ratio is computed using the equation $\frac{S}{N} = 10 \ log_{10}\left(\frac{\bar{x}^2}{\sigma^2}\right)$ in decibels [8].

4. Taguchi Model for Tensile Properties

T he variables used for the test are shown in Table 3. It is considered in the experiment nine levels L9, 3^3 orthogonal arrays. Nine experimental runs were selected. The total number of degrees of freedom is calculated. In this research nine experiments are conducted with different cryogenic variables. The sample tensile specimens were prepared and tested for tensile behavior. The S/N ratios are also calculated. The results of tensile strength in each of the nine trial are given in Table 3.

Table 3: Design of Experiments

Exp. NO.	Factors		
	A Cryogenic -Temperature ^{0}C	B Treatment duration hr	C Wt.% of Al_20_3
1	-100	0	0
2	-100	25	10
3	-100	50	20
4	-150	0	20
5	-150	25	0
6	-150	50	10
7	-196	0	10
8	-196	25	20
9	-196	50	0

Table 4: Experimental Observations for Tensile Test as per DOE

Exp. NO.	Factors			Tensile test results			Average	Standard deviation	S/N ratio
	A	B	C	1	2	3			
1	-100	0	0	120	117	118	118	1.6	37
2	-100	25	10	167	164	165	165	1.5	41
3	-100	50	20	205	205	205	205	0.3	56
4	-150	0	20	190	188	191	190	1.4	42
5	-150	25	0	191	189	190	190	1.0	45
6	-150	50	10	161	159	161	161.	0.9	44
7	-196	0	10	195	192	194	194	1.6	41
8	-196	25	20	193	191	193	192	0.9	46
9	-196	50	0	184	183	184	184	0.6	49

5. Mean of Mean methodfor Maximum Tensile strength

The experiments were conducted as per the above table and the tensile strength of the MMC was found out for various parameters. The results are plotted inFig.1to Fig. 3. The mean of mean tensile strength for the three parameters selected cryogenic temperature; exposure duration and effect of alumina particle are plotted.

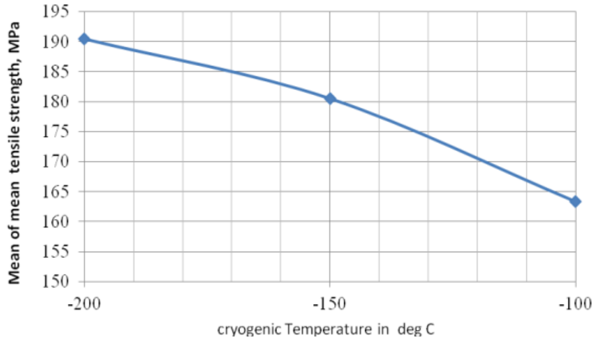

Fig. 1 Effect of Cryogenic Temperature on Average of Mean Tensile Strength of Al_2O_3Composites.

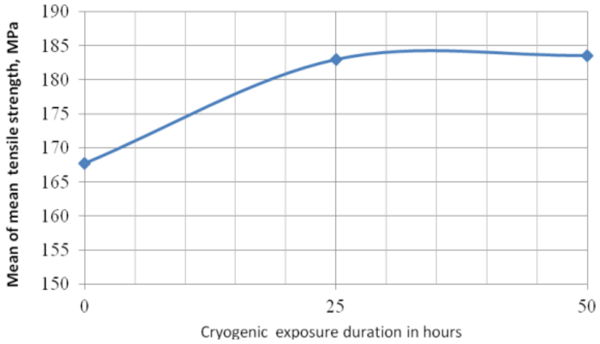

Fig. 2 Effect of Cryogenic Temperature Exposure Duration on Mean of Mean Tensile Strength. of Al_2O_3 Composites

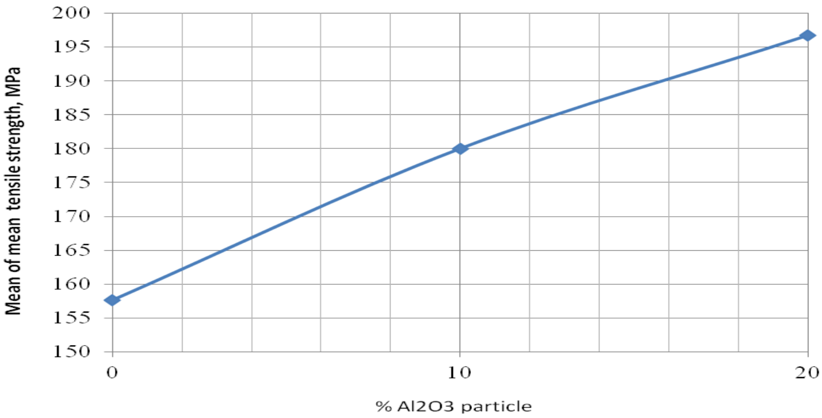

Fig. 3 Effect of Al_2O_3 Particulate on Average of Mean Tensile Strength of Al_2O_3Composites.

6. S/N Ratio Method for maximum Tensile strength.

The results of experimental values using S/N ratio exhibits the best combinations of parameters resulting in maximum tensile strength. The optimum condition for tensile strength as shown in Fig. 4 to 6 and the optimum parameters show -196°C of cryogenic temperature, 50 hours of cryogenic exposure time and 20 wt.% of Al_2O_3 particles. The optimal set of values of control factors for better tensile strength of cryogenically treated MMCs were arrived at.

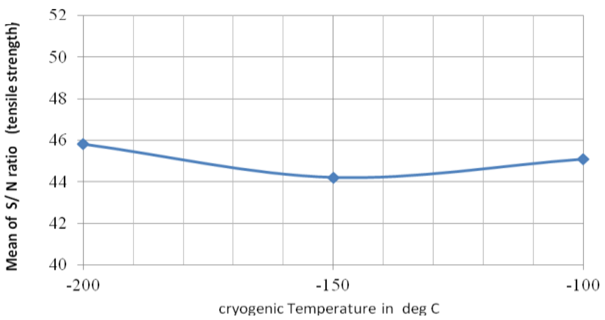

Fig.4 Effect of Cryogenic Temperature on Average S/N Ratio on Tensile Strength of Al/Al_2O_3 Composites.

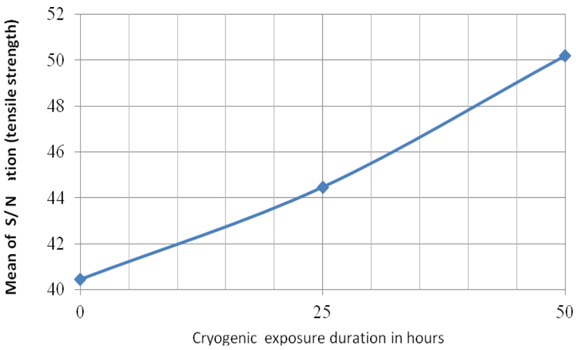

Fig.5 Effect of Cryogenic Exposure Duration on Average S/N Ratio on Tensile Strength of Al/Al_2O_3 Composites

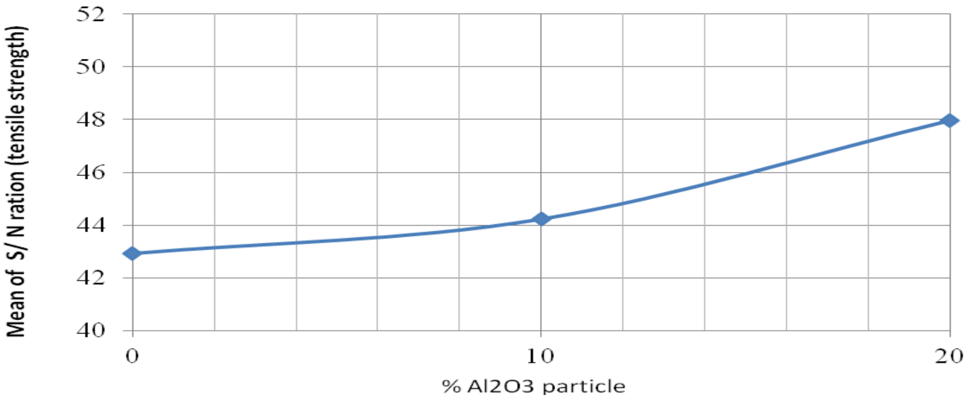

Fig.6 Effect of wt. % of Al_2O_3 on Mean S/N Ratio on Tensile Strength of Al/Al_2O_3 Composites

7. ANOVA Design Table

The ANOVA table exhibited in Table 5 indicates the performance for the optimum condition. Such a condition is determined based on the quality characteristics selected for the analysis. At different levels. It is seen that, the percentage contribution is more significant for the optimum outcome of the factors. The optimum conditions obtained in the ANOVA table can be used to obtain the participative results and which can contribute a significant task while working on various tests.

Table 5: ANOVA Design Table for Tensile Strength of Cryogenic Treated Al_2O_3 /Al Composites.

actor		A	B	C	Total
Sum at factor level	1	489.9	503.3	493.28	1602.8
	2	541.5	548.9	521.02	
	3	571.4	550.7	588.51	
Sum of square difference		10198	4329	14393	28921
Degree of freedom		02	02	02	06
% Contribution		35	15	50	100
Optimum Level		03	03	03	
		-200 °C	50h	20 wt.%	

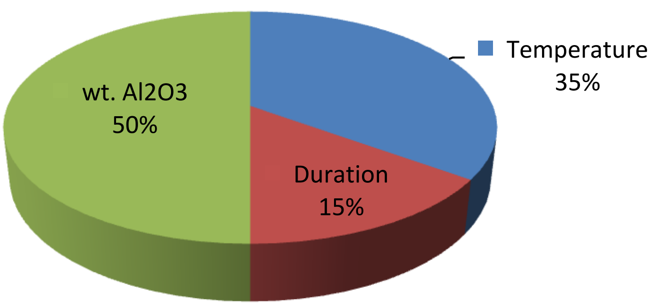

Fig. 7: Percentage Contribution of Parameters on Tensil Properties

	Mean of mean values	S/N ratio
Level	Combination	Combination
Tensile strength (MPa)	A3B3C3	A3B3C3

This step was utilized to review a number of different analyses to have a better interpretation among the different experimental results. By the analysis of variance (ANOVA) it is clear that the percentage contribution of cryogenic temperature is 35%, cryogenic exposure duration is 15 % and wt. % Al_2O_3 is 50 %. The quality characteristics are as shown in Table 5 and are plotted in pie chart shown in Fig 7.

8. Confirmation test

After obtaining the optimal parameters through mathematical approach, it is required to conduct experiments to validate the analytical results. Such experiments are conducted. The actual confirmation tests were conducted to assess the tensile behaviour with parameter levels that are different from those used for ANOVA analysis. The parameter levels used for the confirmation tests are shown in Table 6. The results of the confirmation test are compared with the computed values [7].

9. Results & discussion

Experimental investigations were carried out to validate the analytical results by Taguchi approach to optimise the process parameters at a cryogenic temperature of -196^{0}C.The variables were holding time at -196 ^{0}C and % reinforcement [8].

Table 6:Confirmation Experimental results

Cryo- treatment duration	UTS	UTS	UTS	UTS	UTS
	MPa	MPa	MPa	MPa	MPa
% Alumina	0%	5%	10%	15%	20%
0	118	124	167	185	187
10	127	138	175	201	203
20	133	144	183	207	209
30	133	145	183	209	212
40	141	155	191	214	216
50	144	162	197	218	220

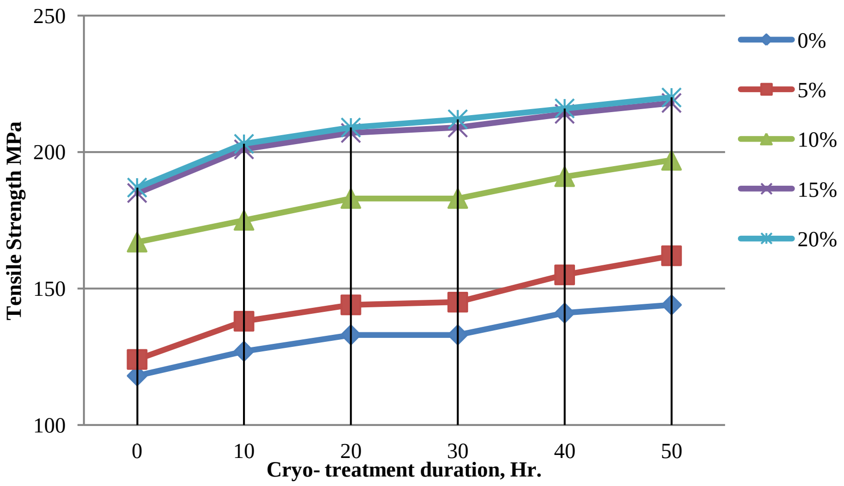

Fig.8: Confirmation test results

The confirmation test results reveal that the values for tensile properties are found to be in agreement with the values obtained by Taguchi approach. Thus design of experiments by Taguchi method was successfully used to predict the properties of composites [9].

10. Conclusions

Based on the study of the tensile properties of both as-cast and cryo-treated Aluminium 6061 alloy and Aluminium-Alumina MMC, the following conclusions are drawn: Taguchi method and S/N ratio method used to optimise the process variables minimized the actual number of experiments to be conducted in order to determine the tensile properties of cryo-treated Aluminium composites were found fruitful. The concepts of ANOVA computations, S/N ratio calculations and Orthogonal array computations used. After obtaining the optimum process variables, the validation experiment was conducted. The process variables at optimal condition in order to obtain best tensile properties of the MMC are 20 % of alumina particles by weight, cryo-temperature of -200°C and cryo-treatment duration of 50 hours. It is observed from the ANOVA table that the cryogenic temperature (A = 35%), cryogenic exposure time (B= 15%) and wt. % of Al_2O_3 particulate (C=50%) have great influence on the compression strength.

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