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# Multi-Objective Optimization of friction stir welded dissimilar aluminium composites using grey analysis

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**Abstract**

This paper focus on optimization of Friction Stir Welding (FSW) process parameters for joining of disparate aluminium composites using hybrid approach. The FSW process parameters considered are tool rotational speed, tool profile, axial force and aluminium material. Response Surface Method (RSM) of central composite design is used for determining the experiment. The quality characteristics considered are hardness (H) and tensile strength (TS). Ideal mix of process parameters is dictated by the grey relational grade (GRG) obtained through GRA for numerous performance characteristics. Analysis of Variance (ANOVA) is employed to determine the contribution of FSW process parameters.

**Keywords:** FSW, Hardness, Tensile Strength, RSM, GRG.

## INTRODUCTION

Aluminium has wide application in the field of aerospace, automobile, railways etc because of light weight and high strength to weight ratio[1] .Similarly Aluminium metal composites(AMC) also have distinct advantages and it is used in above mentioned fields. AMC can be produced in several techniques like powder metallurgy, mechanical alloying, squeeze casting, compo casting, stir casting etc[2,3].AMC have specific stiffness, good fatigue property, high formability and improved corrosion resistance[4,5]. AMC can be used in friction stir welding since in this process rotating tool moves along joint interface, generates heat and results in recirculating flow of plasticized material near the tool surface. This softened material is subjected to extrusion by the tool pin rotational and traverse movements leading to formation of friction stir processing zone [4].

Friction stir welding is a moderately new solid state joining process during this welding process, a special shaped FSW tool is rotated, plunged and then traversed along the joint to form weld. FSW has been used to weld the monolithic materials such as aluminum, magnesium, steel. Recently, several studies have reported that the FSW produces a high quality weld joint in aluminum based composites [7].The advantage of friction stir welding is it will eliminate all types fusion problem during welding.

Response surface method is an orderly use of outline and examination of investigations for planning and enhancing weld quality. The parameters taken for welding are welding speed, axial load, tool pin profile and material used. Experiments are conducted in modified milling machine by taking above mentioned parameters. From literature [8-11] it is understood there will be influence in tool pin profile used in friction stir welding in literature pin profile like square, hexagon, taper, round, threaded round, threaded taper ,triangle are used from this four influential profile is used in this research work. The output parameters taken for analysis are ultimate tensile strength and hardness. An empirical model for the prediction of ultimate tensile strength and hardness in Friction stir welding process is developed using RSM and optimized using regression analysis[12].

Grey relational analysis [13] is useful for numerous execution qualities in welding process. Grey system theory measure degree[14] measures level of approximation among arrangement using a grey relational grade.GRA[15-16] based on grey system theory can be used to solve complicated interrelationships among various execution qualities adequately. This study presents optimizing performance of characteristics [welding speed, axial load, tool pin profile and material used] of friction welded composite using GRA. The tool rotational speed, welding speed, and tool pin geometry were considered as the process parameters, and the effects on the ultimate tensile strength and percentage of elongation were explored utilizing the Taguchi-based grey relational analysis[18]. FSW experiments are conducted to optimize process parameters (plunge depth,tool rotational speed, welding speed and shoulder diameter) utilizing the Taguchi L18 orthogonal design[19-20].

## EXPERIMENTAL PROCEDURES:

### *Materials*

The plate of dimensions 100mm×50×6mm are obtained in modified stir casting with different weight percentage of reinforcement and different matrix materials are friction stir welded in modified vertical milling machine.In stir casting different weight percentage of Powdered Activated Carbon (PAC) is added with AA6061 and AA7075 aluminium alloy, various test were conducted in the fabricated carbon from the test value obtained AA6061 with 6% activated carbon and AA7075 with 6% activated carbon as reinforcement has given good mechanical property so that composite is chosen for welding.

***FSW process***

A vertical milling machine was utilized for the joining of the composite plates. The parameters taken for this welding are welding speed,axial load, tool pin profile and Aluminium Material Used.The butt welding is carried out in AA6061 alloy,AA7075 alloy,AA6061 Reinforced Activated carbon and AA7075 Reinforced Activated carbon composite plates. Tool selected for performing welding is high speed steel tool with four different probe shapes such as Square,Taper,Triangle.Round and threaded round with tool length 70mm, shoulder diameter 16mm and probe length of 5.8mm. The level chosen for four parameters Speed (N),Axial Load (F),Tool Profile (P) and Aluminium Material.The range taken for speed is 1000,1100,1200 and 1400 rpm,for Axial Load 8,9,10,11and12KN,Tool Profile used are Taper(Level -2), Cylindrical(Level -1,Square(Level -0),T.Cylindrical (Level 1)and Triangle(Level 2),Aluminium Materials used are AA6061alloy- AA6061alloy plate(Level -2),AA6061 reinforced Activated carbon composite- AA7075 reinforced Activated carbon composite(Level -1),AA6061 reinforced Activated carbon composite- AA6061 reinforced Activated carbon composite(Level -0), AA7075 reinforced Activated carbon composite- AA7075 reinforced Activated carbon composite (Level 1)and AA6061alloy- AA6061alloy plate (Level 2).

Response surface method of four-factor and five-level central composite design having 31 runs was used to conduct the experiments. As per the design matrix, 31 butt joints were fabricated using the FSW machine. Three tensile specimens were prepared from each of the welded plates obtained by cross segmenting at the inside opposite to the welding heading according to ASTM E08 standard. The ultimate tensile strength (UTS) was evaluated using a computerized universal tensile testing machine.

***Welding responses***

The ultimate tensile strength (UTS) and hardness were considered as the welding process results. Tensile test specimen were set up agreeing to the ASTM E08 specification and tests were conducted in room temperature similarly hardness test also conducted for welded specimen.Table .1 shows the design matrix and experimental results of UTS and hardness

**Table 1.** Design Matrix and Estimated Tensile Strength and Hardness

| Sl.No | Speed (N) | Axial Load (F) | Tool Profile (P) | Aluminium Material Used(M) | Ultimate Tensile Strength (MPa) | Micro Hardness |
|---|---|---|---|---|---|---|
| 1. | 0 | 0 | 0 | 0 | 228.3 | 75.1 |
| 2. | 1 | -1 | 1 | 1 | 206.8 | 67.2 |
| 3. | -1 | -1 | 1 | 1 | 173.6 | 58.9 |
| 4. | 0 | 0 | 0 | -2 | 178.9 | 59.7 |
| 5. | -1 | 1 | -1 | 1 | 191 | 61.2 |
| 6. | 0 | 0 | 0 | 0 | 233.4 | 76.7 |
| 7. | 1 | -1 | -1 | 1 | 196.3 | 65.2 |
| 8. | 1 | -1 | -1 | -1 | 183.9 | 58.9 |
| 9. | 0 | 0 | -2 | 0 | 132 | 35 |
| 10. | 1 | -1 | 1 | -1 | 192 | 60.8 |
| 11. | 0 | 0 | 0 | 0 | 231.1 | 76.7 |
| 12. | -1 | -1 | -1 | -1 | 191.1 | 61.2 |
| 13. | -1 | -1 | -1 | 1 | 189 | 67.2 |
| 14. | 0 | -2 | 0 | 0 | 231 | 77.2 |
| 15. | 2 | 0 | 0 | 0 | 218 | 71.5 |
| 16. | 0 | 0 | 0 | 0 | 231.1 | 76.7 |
| 17. | 1 | 1 | -1 | -1 | 172.1 | 53.9 |
| 18. | 0 | 2 | 0 | 0 | 205.3 | 65.1 |
| 19. | 0 | 0 | 2 | 0 | 115.8 | 31.6 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 20. | 0 | 0 | 0 | 0 | 230.4 | 75.8 |
| 21. | -1 | -1 | 1 | -1 | 176.8 | 55.6 |
| 22. | -1 | 1 | 1 | -1 | 155.1 | 50.2 |
| 23. | 1 | 1 | 1 | -1 | 171.1 | 57.7 |
| 24. | 0 | 0 | 0 | 0 | 233 | 77.4 |
| 25. | 1 | 1 | 1 | 1 | 198.3 | 62.3 |
| 26. | 0 | 0 | 0 | 2 | 198.1 | 65.7 |
| 27. | -1 | 1 | -1 | -1 | 179.2 | 57.3 |
| 28. | -1 | 1 | 1 | 1 | 164 | 50.6 |
| 29. | 0 | 0 | 0 | 0 | 231.1 | 76.7 |
| 30. | -2 | 0 | 0 | 0 | 191 | 65.3 |
| 31. | 1 | 1 | -1 | 1 | 195.9 | 59. |

**GREY RELATIONAL ANALYSIS**

GRA is connected to find out the best selection of machining parameters for any machining process. According to the RSM design 31 sets of experiments are chosen for the experimentation and ultimate tensile strength and hardness is found out. In GRA technique we have larger the better and smaller the better expressions for the purpose of optimizing the ranges depending on application. Here, we considered larger the better expression because larger the value better will be the bond strength since we concentrated on the bond strength of the weldment. Larger the better, grey relational coefficient and grey relational grade expressions are appeared in (a),(b),(c),

The following formulas are applied to find the Normalizing the experimental results, Grey relational coefficient and Grey relational grade.

**(a)** For higher the better quality and lower the better quality, Normalizing the experimental results is given by,

$$Xi(k) = \left(yi(k) - min\, yi(k)\right) / \left(max\, yi(k) - min\, yi(k)\right)$$

$$Xi(k) = \left(max\, yi(k) - yi(k)\right) / \left(max\, yi(k) - min\, yi(k)\right)$$

Where,

$Xi(k)$ is the value after grey relation generation

min $yi(k)$ is the smallest value of $yi(k)$ for the k$^{th}$ response

max $yi(k)$ is the largest value of $yi(k)$ for the k$^{th}$ response.

**(b)** Calculating the grey relational coefficient from the normalized values yield.

$$\gamma\left(xo(k), xi(k)\right) = \left(\Delta min + \zeta\, \Delta max\right) / \left(\Delta oj(k) + \zeta\, \Delta max\right)$$

Where,

j=1,2...n; k=1,2...m, n is number of experimental data and m is number of responses.

$Xo(k)$ is reference sequence ( $xo(k)=1,\ k=1,\ 2...m$ ); $xj(k)$ is specific comparison sequence.

$\Delta oj = \| xo(k) - xj(k) \|$ = The absolute value of the difference between $xo(k)$ and $xj(k)$.

$\Delta min = minmin\| xo(k) - xj(k) \|$ is the smallest value of $xj(k)$.

$\Delta max = maxmax\| xo(k) - xj(k) \|$ is the largest value of $xj(k)$.

ζ is the distinguishing coefficient in the range $0 \leq \zeta \leq 1$ (the value may adjusted based on the practical needs of the system).

**(c)** Calculating the grey relational grade is done by averaging the grey relational coefficient which yields:

$$\gamma j = 1/k\Sigma\ \gamma ij \qquad (4)$$

γj is grey relational grade for jth experiment and k is number of performance characteristics.

The normalized data results for hardness and UTS is shown in table 2, the grey relational co-efficient from normalized values for hardness and UTS is appeared in table 3 and Influence of process parameters of grey relational grade is shown in table 4

**Table 2.** Normalized data results

| Sl.No | Hardness | Ultimate Tensile Strength (UTS) | Normalized Hardness | Normalized UTS |
|---|---|---|---|---|
| 1 | 75.1 | 228.3 | 0.949781659 | 0.040102389 |
| 2 | 67.2 | 206.8 | 0.777292576 | 0.223549488 |
| 3 | 58.9 | 173.6 | 0.596069869 | 0.506825939 |
| 4 | 59.7 | 178.9 | 0.613537118 | 0.461604096 |
| 5 | 61.2 | 191 | 0.64628821 | 0.358361775 |
| 6 | 76.7 | 233.4 | 0.984716157 | -0.003412969 |
| 7 | 65.2 | 196.3 | 0.733624454 | 0.313139932 |
| 8 | 58.9 | 183.9 | 0.596069869 | 0.41894198 |
| 9 | 35 | 132 | 0.074235808 | 0.861774744 |
| 10 | 60.8 | 192 | 0.637554585 | 0.349829352 |
| 11 | 76.7 | 231.1 | 0.984716157 | 0.016211604 |
| 12 | 61.2 | 191.15 | 0.64628821 | 0.357081911 |
| 13 | 67.2 | 189 | 0.777292576 | 0.375426621 |
| 14 | 77.2 | 231 | 0.995633188 | 0.017064846 |
| 15 | 71.5 | 218 | 0.871179039 | 0.127986348 |
| 16 | 76.7 | 231.1 | 0.984716157 | 0.016211604 |
| 17 | 53.9 | 172.1 | 0.486899563 | 0.519624573 |
| 18 | 65.1 | 205.3 | 0.731441048 | 0.236348123 |
| 19 | 31.6 | 115.8 | 0 | 1 |
| 20 | 75.8 | 230.4 | 0.965065502 | 0.0221843 |
| 21 | 55.6 | 176.8 | 0.524017467 | 0.479522184 |
| 22 | 50.2 | 155.1 | 0.406113537 | 0.664675768 |
| 23 | 57.7 | 171.1 | 0.569868996 | 0.528156997 |
| 24 | 77.4 | 233 | 1 | 0 |
| 25 | 62.3 | 198.3 | 0.670305677 | 0.296075085 |
| 26 | 65.7 | 198.1 | 0.744541485 | 0.29778157 |
| 27 | 57.3 | 179.2 | 0.561135371 | 0.459044369 |
| 28 | 50.6 | 164 | 0.414847162 | 0.588737201 |
| 29 | 76.7 | 231.1 | 0.984716157 | 0.016211604 |
| 30 | 65.3 | 191 | 0.73580786 | 0.358361775 |
| 31 | 59 | 195 | 0.598253275 | 0.324232082 |

**Table 3.** Grey relational coefficients for each execution co-efficient

| Sl.No | Hardness | Ultimate Tensile Strength (UTS) | Grey coefficient of Hardness | Grey coefficient of UTS |
|---|---|---|---|---|
| 1 | 75.1 | 228.3 | 0.925750395 | 0.350692521 |
| 2 | 67.2 | 206.8 | 0.691037736 | 0.41980198 |
| 3 | 58.9 | 173.6 | 0.496610169 | 0.50170068 |
| 4 | 59.7 | 178.9 | 0.519964508 | 0.490213136 |
| 5 | 61.2 | 191 | 0.58250497 | 0.461891644 |
| 6 | 76.7 | 233.4 | 1.006872852 | 0.331812999 |
| 7 | 65.2 | 196.3 | 0.614900315 | 0.448470588 |
| 8 | 58.9 | 183.9 | 0.544103993 | 0.478879502 |
| 9 | 35 | 132 | 0.36716792 | 0.576589595 |
| 10 | 60.8 | 192 | 0.588353414 | 0.459409594 |
| 11 | 76.7 | 231.1 | 0.968595041 | 0.340461452 |

| | | | | |
|---|---|---|---|---|
| 12 | 61.2 | 191.15 | 0.583374813 | 0.46152079 |
| 13 | 67.2 | 189 | 0.571150097 | 0.466787989 |
| 14 | 77.2 | 231 | 0.9669967 | 0.340832396 |
| 15 | 71.5 | 218 | 0.796195652 | 0.385744235 |
| 16 | 76.7 | 231.1 | 0.968595041 | 0.340461452 |
| 17 | 53.9 | 172.1 | 0.490376569 | 0.504858471 |
| 18 | 65.1 | 205.3 | 0.679026651 | 0.424078624 |
| 19 | 31.6 | 115.8 | 0.333333333 | 0.6 |
| 20 | 75.8 | 230.4 | 0.95751634 | 0.343049327 |
| 21 | 55.6 | 176.8 | 0.510452962 | 0.494827586 |
| 22 | 50.2 | 155.1 | 0.429304029 | 0.538037052 |
| 23 | 57.7 | 171.1 | 0.486307054 | 0.506941523 |
| 24 | 77.4 | 233 | 1 | 0.333333333 |
| 25 | 62.3 | 198.3 | 0.628081458 | 0.443230404 |
| 26 | 65.7 | 198.1 | 0.626737968 | 0.443758899 |
| 27 | 57.3 | 179.2 | 0.521352313 | 0.489547038 |
| 28 | 50.6 | 164 | 0.459247649 | 0.52124183 |
| 29 | 76.7 | 231.1 | 0.968595041 | 0.340461452 |
| 30 | 65.3 | 191 | 0.58250497 | 0.461891644 |
| 31 | 59 | 195 | 0.606625259 | 0.451824135 |

**Table 4.** Impact of process parameters of grey relational grade

| Sl.No | Hardness | Ultimate Tensile Strength (UTS) | Grade | Order |
|---|---|---|---|---|
| 1 | 75.1 | 228.3 | 0.553702353 | 13 |
| 2 | 67.2 | 206.8 | 0.579342867 | 3 |
| 3 | 58.9 | 173.6 | 0.558213703 | 11 |
| 4 | 59.7 | 178.9 | 0.539638685 | 25 |
| 5 | 61.2 | 191 | 0.542125507 | 24 |
| 6 | 76.7 | 233.4 | 0.553702353 | 14 |
| 7 | 65.2 | 196.3 | 0.589054281 | 1 |
| 8 | 58.9 | 183.9 | 0.574990613 | 4 |
| 9 | 35 | 132 | 0.563413767 | 9 |
| 10 | 60.8 | 192 | 0.565279199 | 8 |
| 11 | 76.7 | 231.1 | 0.553702353 | 15 |
| 12 | 61.2 | 191.15 | 0.553861449 | 12 |
| 13 | 67.2 | 189 | 0.567925117 | 6 |
| 14 | 77.2 | 231 | 0.579501963 | 2 |
| 15 | 71.5 | 218 | 0.574831517 | 5 |
| 16 | 76.7 | 231.1 | 0.553702353 | 16 |
| 17 | 53.9 | 172.1 | 0.549191003 | 21 |
| 18 | 65.1 | 205.3 | 0.5368 | 27 |
| 19 | 31.6 | 115.8 | 0.543990939 | 23 |
| 20 | 75.8 | 230.4 | 0.553702353 | 17 |
| 21 | 55.6 | 176.8 | 0.544150035 | 22 |
| 22 | 50.2 | 155.1 | 0.5239 | 31 |
| 23 | 57.7 | 171.1 | 0.539479589 | 26 |
| 24 | 77.4 | 233 | 0.553702353 | 18 |

| | | | | |
|---|---|---|---|---|
| 25 | 62.3 | 198.3 | 0.553543257 | 20 |
| 26 | 65.7 | 198.1 | 0.567766021 | 7 |
| 27 | 57.3 | 179.2 | 0.528061839 | 30 |
| 28 | 50.6 | 164 | 0.532414093 | 29 |
| 29 | 76.7 | 231.1 | 0.553702353 | 19 |
| 30 | 65.3 | 191 | 0.532573189 | 28 |
| 31 | 59 | 195 | 0.563254672 | 10 |

**Table 5.** Percentage deviation between experimental and predicted grade

| Sl.No | Hardness | Ultimate Tensile Strength (UTS) | Experimental Grade | Predicted Grade | Percentage Deviation |
|---|---|---|---|---|---|
| 1 | 75.1 | 228.3 | 0.553702353 | 0.554386758 | 0.12361 |
| 2 | 67.2 | 206.8 | 0.579342867 | 0.564266935 | 2.60225 |
| 3 | 58.9 | 173.6 | 0.558213703 | 0.543831468 | 2.57647 |
| 4 | 59.7 | 178.9 | 0.539638685 | 0.554386758 | 2.73295 |
| 5 | 61.2 | 191 | 0.542125507 | 0.543831468 | 0.31468 |
| 6 | 76.7 | 233.4 | 0.553702353 | 0.554386758 | 0.12361 |
| 7 | 65.2 | 196.3 | 0.589054281 | 0.564266935 | 4.20799 |
| 8 | 58.9 | 183.9 | 0.574990613 | 0.564266935 | 1.86502 |
| 9 | 35 | 132 | 0.563413767 | 0.554386758 | 1.6022 |
| 10 | 60.8 | 192 | 0.565279199 | 0.564266935 | 0.17907 |
| 11 | 76.7 | 231.1 | 0.553702353 | 0.554386758 | 0.12361 |
| 12 | 61.2 | 191.15 | 0.553861449 | 0.543831468 | 1.81092 |
| 13 | 67.2 | 189 | 0.567925117 | 0.543831468 | 4.2424 |
| 14 | 77.2 | 231 | 0.579501963 | 0.554386758 | 4.33393 |
| 15 | 71.5 | 218 | 0.574831517 | 0.574831517 | 0 |
| 16 | 76.7 | 231.1 | 0.553702353 | 0.554386758 | 0.12361 |
| 17 | 53.9 | 172.1 | 0.549191003 | 0.564266935 | 2.74512 |
| 18 | 65.1 | 205.3 | 0.5368 | 0.554386758 | 3.27622 |
| 19 | 31.6 | 115.8 | 0.543990939 | 0.554386758 | 1.91103 |
| 20 | 75.8 | 230.4 | 0.553702353 | 0.554386758 | 0.12361 |
| 21 | 55.6 | 176.8 | 0.544150035 | 0.543831468 | 0.05854 |
| 22 | 50.2 | 155.1 | 0.5239 | 0.543831468 | 3.80444 |
| 23 | 57.7 | 171.1 | 0.539479589 | 0.564266935 | 4.59468 |
| 24 | 77.4 | 233 | 0.553702353 | 0.554386758 | 0.12361 |
| 25 | 62.3 | 198.3 | 0.553543257 | 0.564266935 | 1.93728 |
| 26 | 65.7 | 198.1 | 0.567766021 | 0.554386758 | 2.35647 |
| 27 | 57.3 | 179.2 | 0.528061839 | 0.543831468 | 2.98632 |
| 28 | 50.6 | 164 | 0.532414093 | 0.543831468 | 2.14445 |
| 29 | 76.7 | 231.1 | 0.553702353 | 0.554386758 | 0.12361 |
| 30 | 65.3 | 191 | 0.532573189 | 0.532573189 | 0 |
| 31 | 59 | 195 | 0.563254672 | 0.564266935 | 0.17972 |

## DEVELOPMENT OF REGRESSION MODEL

To set up a numerical model for GRG, a regression analysis was performed utilizing the uncoded four a parameters at five levels. The model was tried at a greatest certainty level. In this unique circumstance, a quadratic model that included both the direct and collaboration terms was created, as appeared in the accompanying expressions,

***Regression Equation***

$$Hardness = 73.2 + 0.0147\,Speed(N) - 2.78\,Axial\ Load(F) - 1.14\,Tool\ Profile(P) + 2.00\,Aluminium\ Material\ Used(M)$$

$$UTS = 174.9 + 0.0627\,Speed(N) - 5.58\,Axial\ Load(F) - 3.88\,Tool\ Profile(P) + 5.51\,Aluminium\ Material\ Used(M)$$

$$Grade = 0.54944 + 0.000103\,Speed(N) - 0.011927\,Axial\ Load(F) - 0.004624\,Tool\ Profile(P) + 0.006801\,Aluminium\ Material\ Used(M)$$

It can be seen that the model is communicated as an element of the principle procedure parameters and their cooperation. An information set (predicted value) was built utilizing the model. The genuine value and predicted value of GRG are accounted in Table 5 and Fig. 1. The error gap between predicted and actual values of y (GRG) ranges between 0 and 4.5 %. The ampleness of the model is tried utilizing $R^2$. $R^2$ peaks to the quality of the model and takes an incentive in the vicinity of 0 and 1On the off chance that the esteem is near 1, it is viewed as that there is a decent connection between's the genuine information and the anticipated information. The $R^2$ of the developed model for GRG is 92.7 %.

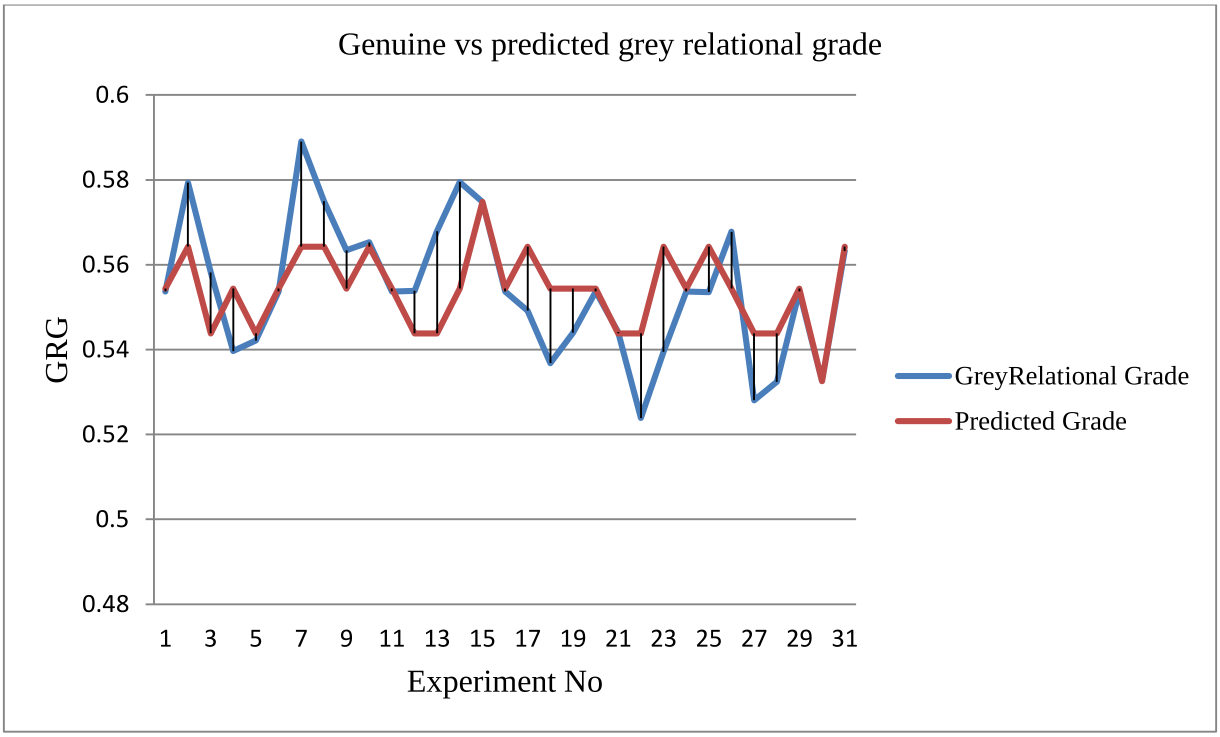


**Figure 1.** Genuine and predicted grey relational grade

***Effect of process parameters on grade***

The contour plot shown in figure 2 clarifies the evaluated response surface for grade regarding speed and axial load. It shows as speed of 1300-1400 rpm and axial load of 8-9 KN, produces high grade. Further increase in axial load grade values decreases. Figure 3 illustrates as increase in speed upto 1400rpm with axial load 9KN produces good hardness further increase in axial load hardness value get reduced. Figure 4 shows as as increase in speed upto 1400rpm with axial load 9KN produces good tensile strength further increase in axial load tensile strength value get reduced. Figure 5 shows the residual plot for grade. From the measurable perspective, it is recommended to examine these residuals for normality, independence, and constant variance when using ANOVA. From the residual plot, it is noticed that none of the assumptions are violated and indicating the perfect fit of the actual and predicted values of response. Hence, this analysis is substantiating the model developed.

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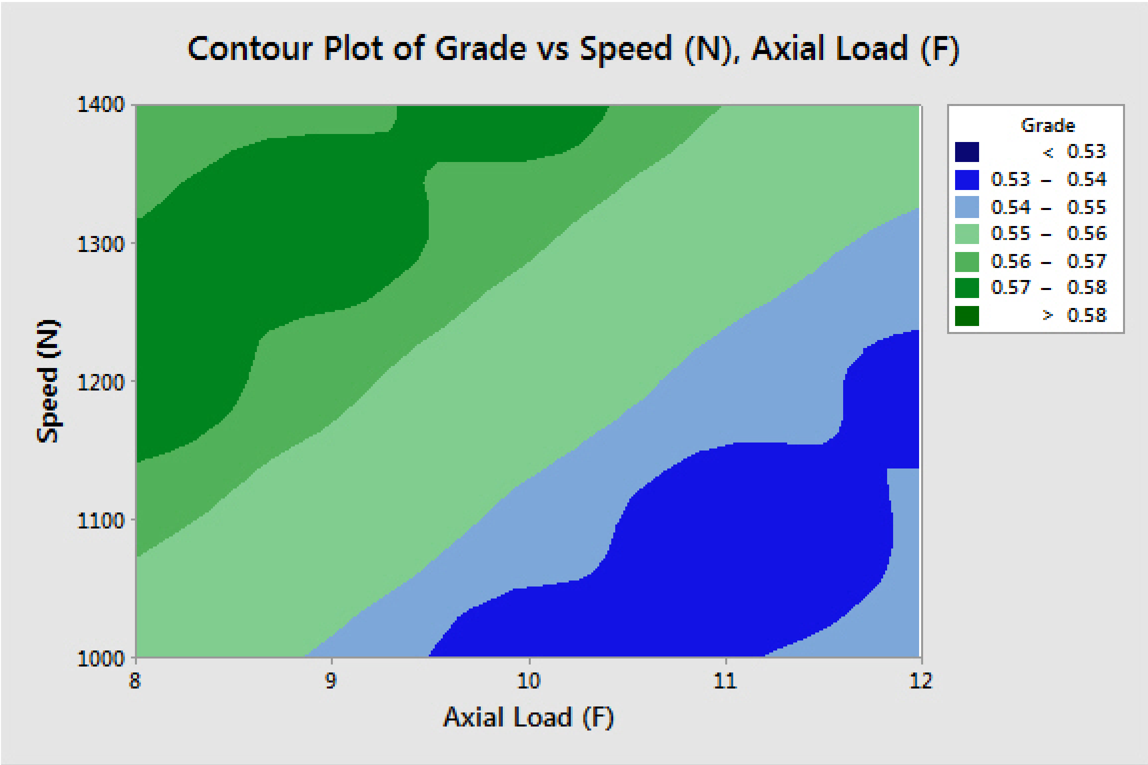


**Figure 2.** Grade vs speed and axial load

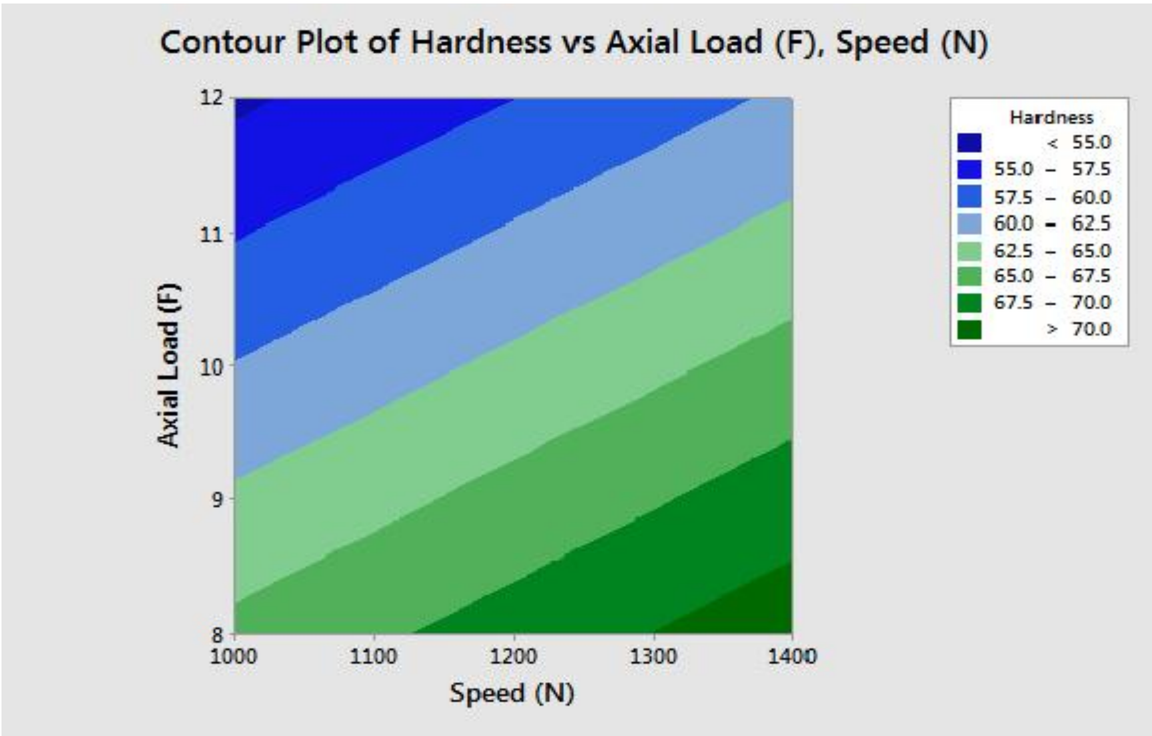


**Figure 3.** Hardness vs axial load and speed

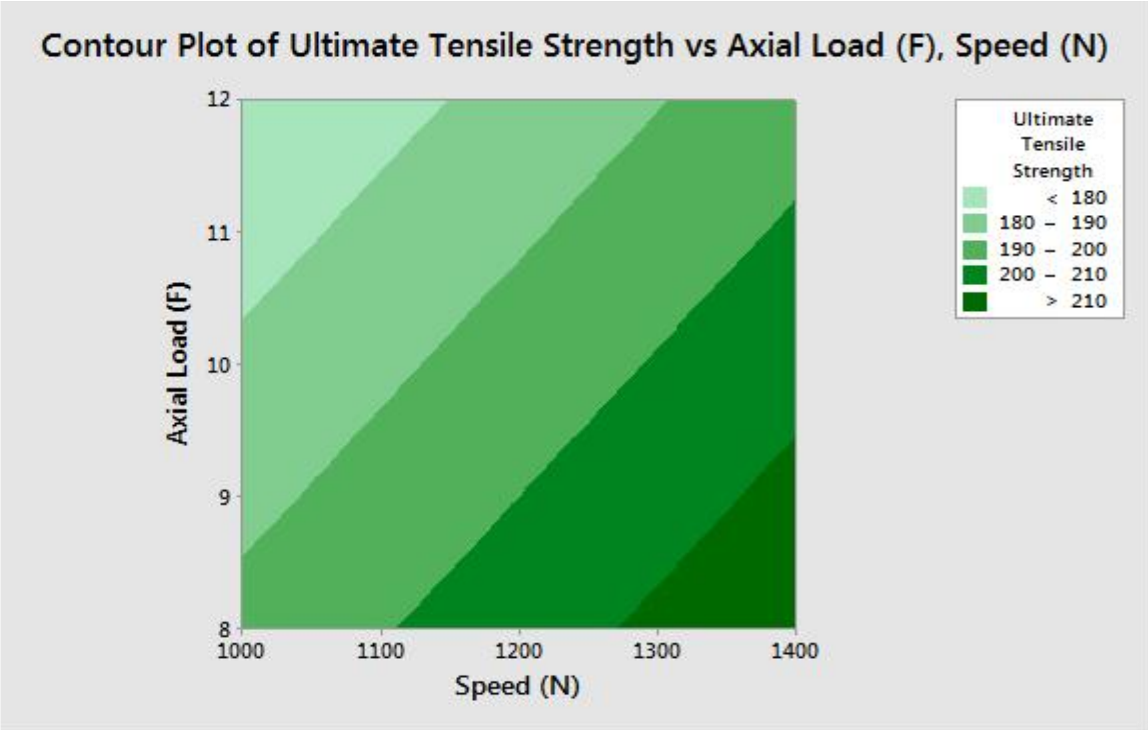


**Figure 4.** Ultimate tensile strength vs axial load and speed

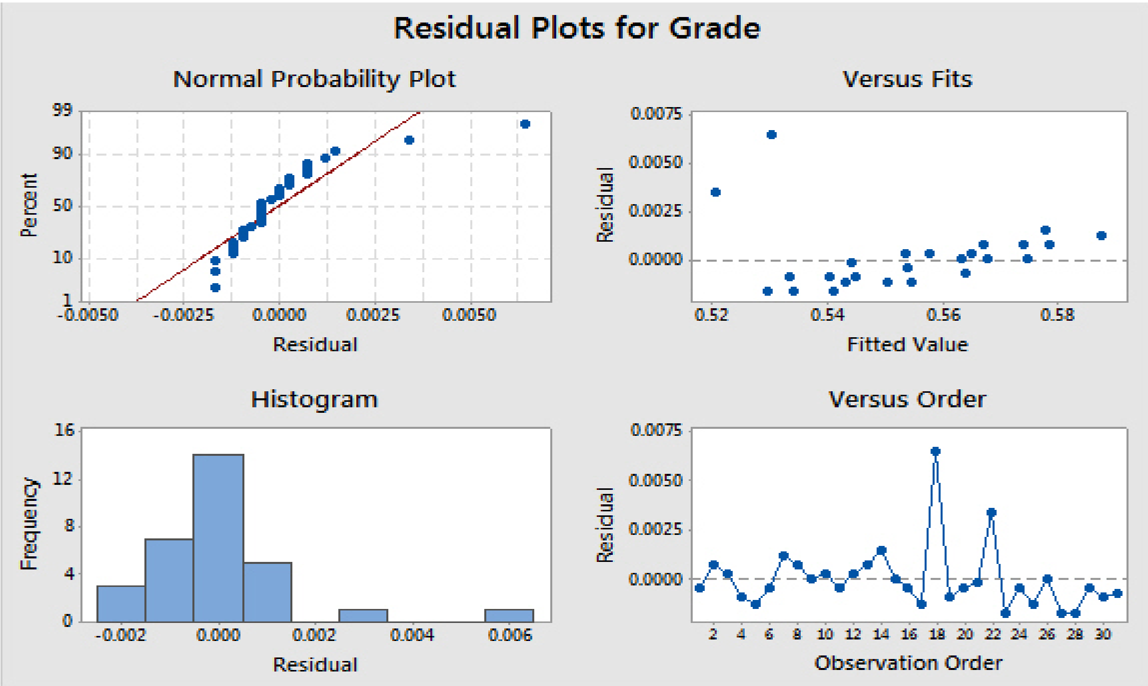


**Figure 5.** Residual plots for grade

***Analysis of Variance***

ANOVA is done in Minitab software. ANOVA is a great analyzing tool to examine which design parameters extensively affect the quality feature. In order to analyze the significance and contribution of each parameters to the GRG value ,ANOVA was carried out and results were shown in table 6.Figure 6 shows the contribution of each parameters in anova and it is listed as axial load have maximum contribution of 45%, followed by speed of 33%,material used 14%,tool profile 7% and error 1%. From the grey relational grade plot in figure 7 the optimal design is identified.

**Table 6.** Analysis of variance for grade utilizing adjusted SS for tests

| Source | DF | Adj SS | Adj MS | F | P | Contribution |
|---|---|---|---|---|---|---|
| Speed | 1 | 0.002563 | 0.002563 | 869.04 | 0 | 33.38 |
| Axial load | 1 | 0.003414 | 0.003414 | 1157.79 | 0 | 44.47 |
| Tool profile | 1 | 0.000513 | 0.000513 | 174.05 | 0 | 6.68 |
| Material used | 1 | 0.001110 | 0.001110 | 376.40 | 0 | 14.45 |
| Error | 26 | 0.000077 | 0.000003 | | | 1.00 |
| Lack of fit | 24 | 0.000077 | 0.000003 | | | |
| Pure | 2 | | | | | |
| Total | 30 | 0.007677 | | | | |

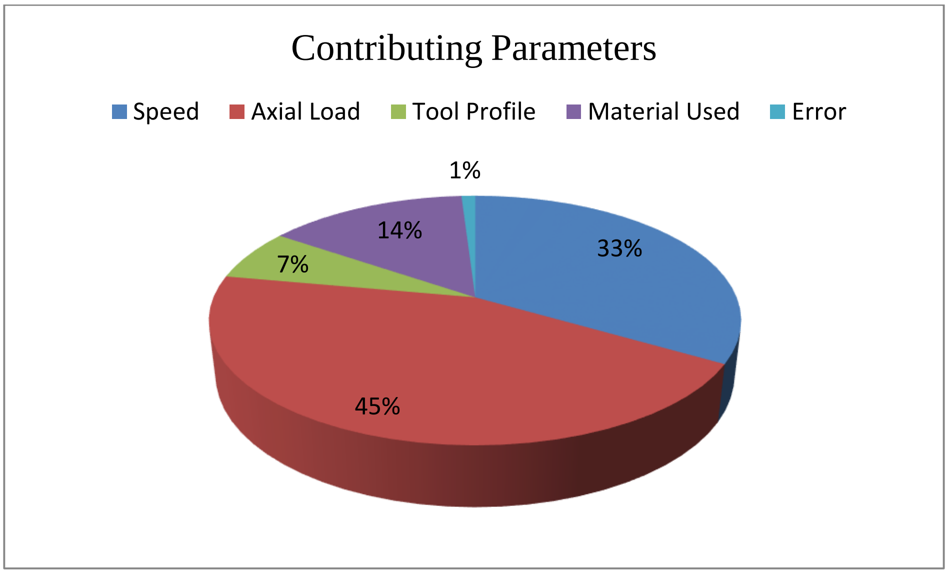


**Figure 6.** Contribution of each welding parameters in ANOVA

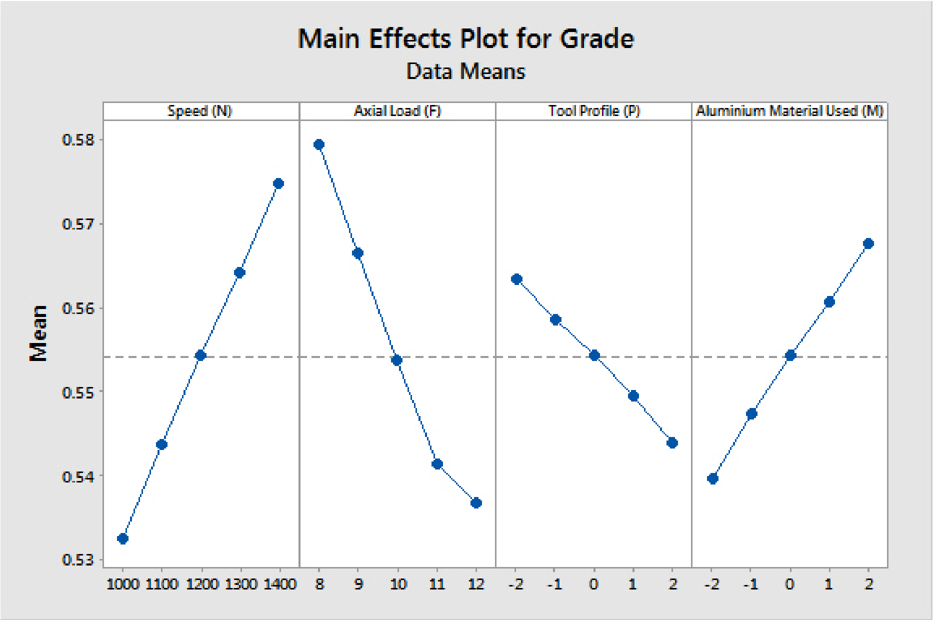


**Figure 7.** Main effect of grey relational grade (GRG)

## CONCLUSIONS

The investigation presents impact of tool rotational speed, tool profile, axial force and aluminium material on weld quality. Thirty one distinctive welding conditions were inspected to find ultimate tensile strength and hardness. The information gathered from the welding tests for two responses were changed into a value GRG as per the response surface method and this GRG value for every welding condition was evaluated to determine the optimal welding conditions. The significance and contribution of each parameter to the GRG value were analyzed by ANOVA. In view of the investigation taking following conclusions can be made,

- According to applied grey based approach, the optimal fsw is experiment 7 with speed 1100rpm, axial load 8KN, cylindrical tool profile and aluminium material AA7075/AA7075 composite.
- The highest UTS value of 233.4 Mpa and highest hardness value of 76.7 is attained in experiment 6 .
- The contribution of each parameters in anova and it is listed as axial load have maximum contribution of 45%, followed by speed of 33%, material used 14%,tool profile 7% and error 1%.
- The investigations performed uncovered that the Rsm-based grey relational analysis effectively upgraded the different friction stir welding process for dissimilar aluminum composites.

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