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Grey Relational Analysis to Determine Optimum Process Parameters for Thermo Mechanical Form Drilling – Riveting

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Abstract

The form drilling riveting is an advanced joining process of aluminum alloys. The purpose of this work is to made new type of form drilling – riveting tool. In addition, the effect of speed rate, feed rate and cone radius ratio on thrust, torque and heat generated were investigated. The significance of influence parameters on their quality characteristics were examined by ANOVA. The optimal combination of parameters for speed and feed were determined based on Signal to Noise ratio. Since the process has multiple performance characteristics, the grey relational analysis is used. The grey relational grade normalizes the contradicting performance indices. From eighteen experiments based on the orthogonal array of L_{18} the best combination of parameters were found. Compared with Taguchi's method the proposed method is more scientific. The experimental results confirm that the proposed method in this study effectively improves the machining performance of Form Riveting process.

Keywords: Form drilling – riveting; ANOVA; Signal to Noise ratio; Grey relational analysis; orthogonal array.

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1. INTRODUCTION

Form riveting, also known as thermal riveting, flow riveting, friction riveting, are nontraditional rivets making method. The heat generated from friction between a rotating conical tool and the work piece is used to soften the work material and penetrate hole [1-7].It forms a bushing directly from the sheet metal work pieces immediately hollow rivet is inserted. The form drilling is modified for friction rivet process. The tool is shown in Fig.(1). The tool has conical portion at the bottom and a shoulder in the cylindrical region and rivets is inserted in shoulder region and rivets were gripped using washers and spring. The tool tip, indents into the work and supports the tool both in radial and axial directions. The friction force on the contact surface produces heat and softens the work material. The tool is then extruded into the work pieces. Once the tool tip penetrates the work pieces, the tool moves further forward to push aside more work material and forms the bushing using cylindrical part of the tool. The copper rivet which is inserted in the shoulder and gripped using washers and spring is driven into predrilled hole with bush immediately under reduced force. Finally, the tool retracts and leaves a hole with rivet on the work piece. The hollow rivet is upsetted using internal mandrel. The purpose of spring controlled washer is to generate friction heat at lower speeds.

The friction riveting has been applied in aeronautical, automobile industries, electronic, bio chemical, and medical instrumentation equipments. Although there outstanding features reveals the distinguished advantages to extend its applications in modern industries. It was suitable to any size of riveting process. Therefore, the novel process of friction riveting needs a further a comprehensive study to understand the effects of riveting on different materials.

Thrust force and torque are key factors in the machining process while considering machining performance. Force and torque are key factors in machining process while considering machining performance. Since torque and thrust force affects the workpiece temperature and hence bushes shape, which provide more solid connection for attachment. On the other hand amount of heat generated which dictates the success of the process. Proper selection of process parameters is essential to obtain quality joints.

2. Grey Relational Analysis

The Grey Relational Analysis (GRA) associated with the Taguchi method represents a rather new approach to optimization. The grey theory is based on the random uncertainty of small samples which developed into an evaluation technique to solve certain problems of system that are complex and having incomplete information. A System for which the relevant information is completely known is a ‘white’ system, while a system for which the relevant information is completely unknown is a ‘black’ system. Any system between these limits is a ‘grey’ system having poor and limited information .Grey Relational Analysis (GRA) a normalization evaluation technique is extended to solve the complicated multi-performance characteristics optimization effectively.

2.1 Data Pre-Processing: Data Pre-Processing is normally required, since the range and unit in one data sequence may differ from others. It is also necessary when the sequence scatter range is too large, or when the directions of the target in the sequences are different.

The formulae are

Larger the better value

$$X_{ij} = \frac{Y_{ij} - \min_i Y_{ij}}{\max_i Y_{ij} - \min_i Y_{ij}} \tag{1}$$

Smaller the better value

$$X_{ij} = \frac{\max_i Y_{ij} - Y_{ij}}{\max_i Y_{ij} - \min_i Y_{ij}} \tag{2}$$

Where yij is the ith performance characteristic in the j^{th} experiment .maxi y ij and mini yij are the maximum and minimum values of i^{th} performance characteristic for alternate j, respectively.

By normalizing, grey relational co-efficient (GRC) is calculated as

$$\cdot_{IJ} = \frac{\min_i \min_j \left| X_J{}^O - X_{IJ} \right| + \varsigma_{\max i} \left| X_J{}^O - X_{IJ} \right|}{\left| X_J{}^O - X_{IJ} \right| + \varsigma_{\max i} \left| X_J{}^O - X_{IJ} \right|} \tag{3}$$

$X_J{}^O$ is the ideal normalized result for the j^{th} performance characteristic. The ideal normalized value is the maximum of the normalized S/N ratio since large normalized S/N ratio is preferred. ζ is the distinguishing or identification co-efficient. Generally it is taken as 0.5. The grey relational grade (GRG) is obtained by averaging the grey relational co-efficient corresponding to each performance measure.

Grey Relational Grade (GRG) $\gamma_i = 1/n \sum_{j=1}^{n} W_K \varsigma_{ij}$ (4)

Here WK denotes the normalized weight factor and taken as 1. The grey relational grade **γi** represents the level of correlation between the reference sequence and the comparability sequence. If the two sequences are identical, then the value of grey relational grade is equal to 1. The grey relational grade also indicates the degree of influence that the comparability sequence could explain over the reference sequence [8- 10].

3. Experimental Method

In this study, the work piece material was Aluminum (Al1100) plates with the dimension of 50x50x3 mm and is riveted by placing one over the other in over lapping fashion. A new form riveting tool of 8 mm in diameter is designed. The form riveting process is carried out using pillar drilling machine with spindle range as 650-750 rpm and 0.15-0.3mm/rev feed rate to conduct experiments. The chemical composition of Aluminum (Al1100) is 99% Al,0.95 Si+Fe,0.20 Cu,0.05Mn and 0.1t0 Zn. Fig.(3) shows the radial drilling machine with friction riveting tool set up. The thrust force and torque was measured using drilling dynamometer and temperature was measure using a temperature gun. Heat generation is calculated from thrust force and velocity of the tool. Form riveted overlapped work pieces is shown in fig. (2).

Fig.1 (a) form drilling tool

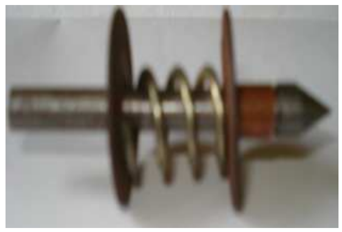

Fig. 1(b) form drilling tool with rivet

Fig.(2). Work pieces with bushing shape and petal formation

Fig.(3). **Radial Drilling Machine with form riveting tool setup**

3.1 Machining Parameter selection and performance evaluation

To perform the experimental design, the levels of machining parameters are selected as in Table 1.

Table 1: Machining Parameter

S.No	Factor	Process Parameters	Units	Level1	Level2	Level3
1	A	r_2/r_1		0.11	0.44	-
2	B	Speed(N)	Rpm	650	700	750
3	C	Feed((S)	mm/rev	0.15	0.2	0.3

Table 2: Experimental Matrix

(L_{18} Orthogonal arrays)

S.NO	A	B	C
1	1	1	1
2	1	1	2
3	1	1	3
4	1	2	1
5	1	2	2
6	1	2	3
7	1	3	1
8	1	3	2
9	1	3	3
10	2	1	1
11	2	1	2
12	2	1	3
13	2	2	1
14	2	2	2
15	2	2	3
16	2	3	1
17	2	3	2
18	2	3	3

Table 3: Computed and Normalized S/N ratio values for Torque

S.No	Thrust force (N)	S/N ratios-Thrust	Normalized S/N ratios-Thrust	GRC S/N ratios-Thrust
1	236	-47.4582	1	0.333
2	248	-47.8890	0.779	0.391
3	258	-48.2324	0.64	0.438
4	245	-47.7833	0.85	0.370
5	275	-48.7867	0.38	0.568
6	287	-49.1576	0.23	0.68
7	248	-47.8890	0.79	0.387
8	295	-49.3964	0.0095	1
9	302	-49.6001	0	1
10	243	-47.7121	0.883	0.38
11	268	-48.5627	0.48	0.510
12	274	-48.7550	0.39	0.516
13	248	-47.8890	0.799	0.385
14	267	-48.5302	0.500	0.5
15	278	-48.8809	0.33	0.604
16	259	-48.2660	0.62	0.446
17	289	-49.2180	0.17	0.7462
18	297	-49.4551	0.02	0.96

4. Analysis and Discussion of Experimental Results

In the form riveting, lower torque and thrust force and higher heat generation are the indications of better performance. For data pre-processing in the grey relational analysis process, torque and thrust force is taken as the 'smaller the better' heat generation rate is taken as the 'larger the better'. L_{18} orthogonal array (OA) is used for the design of experiments. Initially, the S/N ratios for torque thrust and heat generation are computed. Using equations 1 &2 the S/N ratios are normalized and shown in Table 3 ,4and 5. By using the equation (3) the Grey Relational co-efficient is calculated. The value for ζ is taken as 0.5 since both the output parameters are of equal importance (8-11). The grey relational grade can be calculated by using equation (4) which is the overall representative of both the responses which shown in table 6.

Table 4: Computed and Normalized S/N ratio values for Torque

S.No	Torque,N-m	S/N ratios-Torque	Normalized S/N ratios Torque	GRC S/N ratios Torque
1	2.2	-6.8485	1	0.333
2	2.4	-7.6042	0.760	0.2840
3	2.3	-7.2346	0.8789	0.3649
4	2.4	-7.6042	o.760	0.3968
5	2.6	-8.2995	0.55	0.3816
6	2.8	-8.9432	0.35	0.5882
7	2.5	-7.9588	0.65	0.4347
8	2.9	-9.2480	0.26	0.6578
9	3.2	-10.1030	0	1
10	2.4	-7.6042	0.69	0.4201
11	2.6	-8.2995	0.55	0.3816
12	2.7	-8.6273	0.45	0.5263
13	2.6	-8.2995	0.55	0.3816
14	2.7	-8.6273	0.45	0.5263
15	2.9	-9.2480	0.26	0.6578
16	2.5	-7.9588	0.65	0.4347
17	2.9	-9.2480	0.26	0.6578
18	3.2	-10.1030	0	1

Table 5: Computed and Normalized S/N ratio values for Heat generation

S.No	Heat generation,w	S/N Ratio-Heat generation	Normalized S/N ratios heat generation	GRC S/N ratios Heat generation
1	257.02	48.1993	0	1
2	270.09	48.6302	0.12730	0.79706
3	280.98	48.9735	0.22872	0.68613
4	287.35	49.1682	0.28624	0.63887
5	322.99	50.1838	0.58628	0.46028
6	337.09	50.5549	0.69591	0.41809
7	311.64	49.8731	0.49449	0.50277
8	370.70	51.3805	0.93980	0.34727
9	379.50	51.5842	1	0.33333
10	264.64	48.4531	0.08384	0.85639
11	291.87	49.3038	0.32630	0.60510
12	298.40	49.4960	0.38308	0.56620
13	290.86	49.2737	0	0.61169
14	313.15	49.9150	0.12730	0.49659
15	326.05	50.2657	0.31740	0.45025
16	325.46	50.2500	0.50686	0.45214
17	363.16	51.2020	0.61047	0.360469
18	373.22	51.4393	0.60583	0.343126

Table 6: Grey Relational co-efficient and Grey Relational Grades

S.No	GRC Thrust force	GRC Torque	GRC Heat generation	GRG
1.	0.333	0.333	1	0.555
2.	0.391	0.2840	0.79706	0.4906
3.	0.438	0.3649	0.68613	0.4963
4.	0.370	0.3968	0.63887	0.4685
5.	0.568	0.3816	0.46028	0.469
6.	0.68	0.5882	0.41809	0.5621

7.	0.387	0.4347	0.50277	0.4414
8.	1	0.6578	0.34727	0.6683
9.	1	1	0.33333	0.7776
10.	0.38	0.4201	0.85639	0.5521
11.	0.510	0.3816	0.60510	0.4989
12.	0.516	0.5263	0.56620	0.5361
13.	0.385	0.3816	0.61169	0.4594
14.	0.5	0.5263	0.49659	0.5076
15.	0.604	0.6578	0.45025	0.5706
16.	0.446	0.4347	0.45214	0.444
17.	0.7462	0.6578	0.360469	0.588
18.	0.96	1	0.343126	0.7677

Table 7: Response table for GRG

Factor	Level 1	Level 2	Level 3	Rank
A	0.5476	0.5207		3
B	0.522	0.5061	0.6145	2
C	0.4867	0.5366	0.6189	1

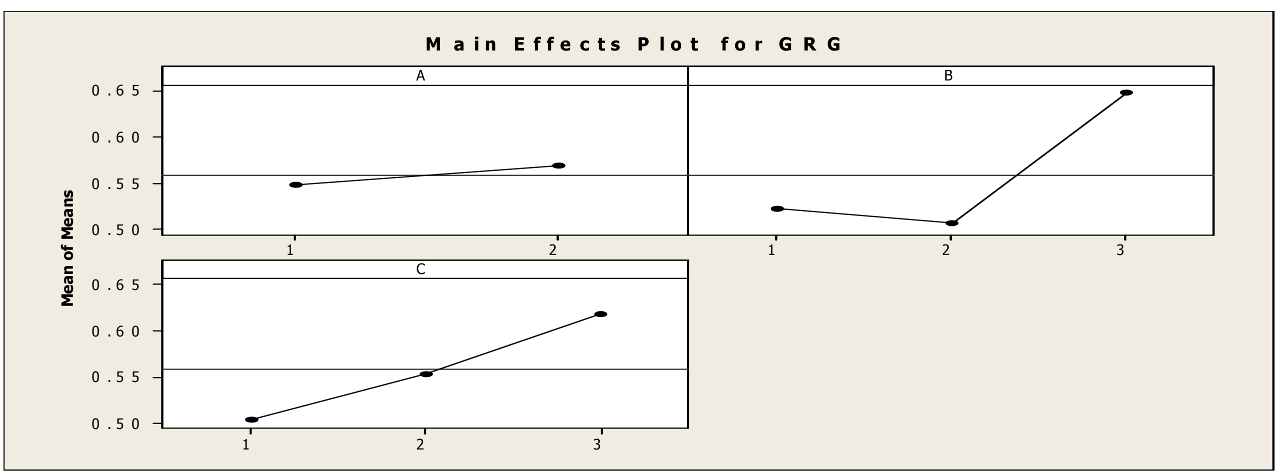

Fig.4. Graphical representation of GRG

6. Results and Discussion

Now, the multiple objective optimization problems have been transformed into a single equivalent objective function optimization problem using this approach. The higher grey relational grade is said to be close to the optimal. The mean response table for overall grey relational grade is shown in Table 7 and is shown in figure (4) graphically. With the help of the response tables and response graph, the optimal parameter combination has been determined as A2, B3, and C3 Using the grey relational grade value, the average value for each factor with respect to each level has been calculated and tabulated in Table 7. From which conclusions may be drawn.

7. Confirmation tests

Once the optimal level of the process parameters is identified, the final step is to predict and validate the improvement of the performance measures using the optimal level. If the predicted and observed S/N ratio values for different responses are close to each other, the effectiveness of the optimal condition can then be ensured. To predict the anticipated improvement under the chosen optimal conditions, the S/N ratio values for torque, thrust and heat generation are calculated using the model for optimal condition. It can be noted that the order of strength of the effects of control factors on the GRG value is C, B and A. As a higher GRG value implies a better quality level, the optimal condition is A2, B3 and C3. The result of the confirmation tests resulted in the improvement of 0.1297 in GRG, after validation.

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