**Utility Theory Embedded Taguchi Optimisation Method in Machining of Graphite Reinforced Polymer Composites (GRPC)**

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**Abstract:**

The present work has concerned by the use of utility embedded Taguchi philosophy to optimize machining constraints with multiple characteristics in machining (milling) operation of graphite reinforced polymer composite (GRPC). L16 orthogonal array has been used to perform the milling operation. Vertical milling centre machine has been used for the milling operation with process parameter such as speed, feed rate, depth of cut as well as weight percentage. The output response considered have Metal removal rate, Thrust, Torque as well as Surface roughness (Ra).The purpose of using this technique to convert the multi-response to single response function. Taguchi method has been used for finding the signal to noise ratio (S/N ratio) which finally function of process parameter. When using the utility theory the main purpose to find the preference number and then find the overall utility. From this study, it has been proven that the Utility based Taguchi method is capable of providing of effective milling environments in order to minimise Thrust, Torque and Surface roughness at the machining slot. This method is suited to off-line quality control of the process as well as applied to mass production lines. Utility theory based Taguchi method has considered to optimise the multiple responses simultaneously, which results the prediction value of S/N ratio is **17.4111** and the mean value is **6.65345** and also obtain the optimal setting value are speed 500mm, feed rate 25mm/rev., depth of cut -1.5mm and weight percentage 40% respectively.

**Keywords:** Graphite reinforced polymer composite, Taguchi method, Utility theory, Utility Taguchi steps.

**1 Introduction**

Recently, optimisation plays a very important role in interdisciplinary area of research work and variety of the research work have been done in the field of machining by pioneer researchers. The main application of graphite reinforced polymer composites in the area of aerospace, space vehicle, automobile sector, electronic insulator and fuselage component of aeroplane etc. The machining (milling) of graphite reinforced polymer performed with four input parameter like- spindle speed, feed rate, depth of cut and weight percentage and the output response like- Metal removal rate (MRR) Thrust, Torque and Surface roughness(Ra). Milling machining is one the second most important machining process after the turning process. The diameter of the milling cutter is 5mm and the tool material is HSS. Taguchi L16 orthogonal array design has been used with vertical milling machine centre has been used for the milling operation. The term utility means the helpfulness of a procedure in orientation to the expectations levels of the customers while performing the machining operation of the number of output characteristics has been used to evaluate the performance. So, the joint amount has been essential to scale its complete performance which are used to the account of the comparative involvement of totally to the excellence features. Overall utility of the process is indicated by index of composite. Utility theory gives the procedural frame­work for the assessment of another features complete through individuals, organizations as well as groups. Basically the Utility theory mentions to the amount of satisfaction in which the each elements gives to the choice maker. Therefore, utility maximisation principal that has been used for the any type of decision. According to the utility theory the decision maker provides best possible decision. Taguchi method has been used for finding the signal to noise ratio (S/N ratio) and also give the optimal setting and also predict the main or highest value with the use of experimental data.

**2 Literature review**

Now a days, the yarn strengthening polymer compound has been used in many area like aerospace application, in industrial field, in the area of automotive parts as well as in making electronic insulator. So, when need very high performance the fibre strengthened polymer compound has been used. Mostly, the fibre-reinforced polymer composites have been categorized through the high strength, low specific weight as well as tough chemical confrontation in contradiction of corrosion [1-3].Epoxy known as polymer resin which have currently help to make the matrix constituents for the fibre-reinforced compounds, which have characteristically epoxy resins. Since the epoxy resins shows outstanding mechanical properties, electrical properties, abrasion resistance, as well as chemical resistance and it has been extensively used in numerous uses like adhesives, coatings as well as laminates [4-6]. Graphite has a one of the most adaptable constituent which is extensively used in industrial scale engineering due to its surprizing physical as well as chemical possessions. Electrical conductivity of graphite, which tends to a metal which has been widely used in electrodes for batteries as well as reactions of electrolysis. There has been a tremendously great current constancy of graphite (700K in air as well as more than 3000K in inert atmosphere) which shows a great application in the manufacture of crucibles to grip molten metal. Great thermal conductivity has been exploited in graphite heat sinks for laptop computers which retain them cool during saving load. Graphite has also cast-off as a filler of electrically conductive material for developing conductive polymer compounds [7-8]. Optimisation of machining parameters has one of noticeable concern in the area of manufacturing, wherever the low-cost of machining operation shows an important part of effectiveness in the market place. Owing to great investment as well as machining prices of NC apparatuses. Nearby, it has been need an investment to drive the numerical control machine such as skilfully as probable in the order to get the essential wage back. Subsequently, the machining of Numerical control machines has been a sensitive to the parameter of machining which best standards have considered earlier a part was put into the production. A numerous investigators has given out the optimization of machining factors, seeing individual operation of turning as well as the graphical techniques has been used to define the best speed as well as feed rate [9–13]. A small number of investigators has been focused on the machining operations of multi point-tool as well as resolved through a forced mathematical programming approaches (S.S. Rao) [14]. Freshly the various procedures have stated in the works to improve the machining constraints of face milling processes.

**3 Experimental Details**

Mostly for finding the machinability of composite an expansive investigation should be required and the L16 orthogonal array has been used for the design of experiment. Taguchi’s based orthogonal array DOE has an effective technique to observe to the influence of machining (milling) parameter by partial number of experimentations. Recently, this revision has been concentrated to calculate the special effects of milling parameter depend on the input process parameter like spindle speed, feed rate, depth of cut and weight percentage. Basically the four level and four factor has been considered Table 1 for the milling operation and subsequently the output response like- thrust, torque, metal removal rate (MRR) and surface roughness (Ra). Taguchi method has also gives the signal to noise ratio (main and mean) and also helps to give the optimal setting for the give data. DOE includes the set of experiments Table 2 which has varied into a consecutive manner aimed at assessing the experimental measurement of responses and it gives the predicted value which shows the highest value and mean value. (**CNC vertical** **machining centre manufactured** by **BHARAT FRITZ WERNER LTD**).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Factors | Unit | Level 1 | Level 2 | Level 3 | Level 4 |
| Speed | [RPM] | 500 | 1000 | 1500 | 2000 |
| Feed rate | [mm/rev] | 150 | 200 | 250 | 300 |
| Depth of cut | [mm] | 0.5 | 1 | 1.5 | 3 |
| Weight % | % | 10 | 20 | 30 | 40 |

**Table 1.** Process parameters and their levels

**Table 2.** Design of experiment (L16) orthogonal array

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| S.No. | Speed (rpm) | Feed rate (mm/rev.) | Depth of cut (mm) | Weight  % |
| 1 | 500 | 10 | -0.5 | 10 |
| 2 | 500 | 15 | -1 | 20 |
| 3 | 500 | 20 | -1.5 | 30 |
| 4 | 500 | 25 | -3 | 40 |
| 5 | 1000 | 10 | -1 | 30 |
| 6 | 1000 | 15 | -0.5 | 40 |
| 7 | 1000 | 20 | -3 | 10 |
| 8 | 1000 | 25 | -1.5 | 20 |
| 9 | 1500 | 10 | -1.5 | 40 |
| 10 | 1500 | 15 | -3 | 30 |
| 11 | 1500 | 20 | -0.5 | 20 |
| 12 | 1500 | 25 | -1 | 10 |
| 13 | 2000 | 10 | -3 | 20 |
| 14 | 2000 | 15 | -1.5 | 10 |
| 15 | 2000 | 20 | -1 | 40 |
| 16 | 2000 | 25 | -0.5 | 30 |

Milling operation has been used for machining of graphite based composite. In machining milling procedure in which the work piece has fed past a revolving cylindrical tool along with multiple revolving cutter edge. The arrangement of the tool is vertical to the feed way and the tool has named as milling cutter. On the other hand cutting edges is named as teeth. Usually, the plane surface have shaped through the machining process. The operation of machining (milling) have used to machining the plane surface. Ultimately, machining operation has considered as upright or rough flanks finished beneficial to the work piece stand to a flat revolving plate. Milling operation is categorized like knee-type as well as cutter cover a figure of cutting parameters. The accurateness of the milling machining have much superior in comparison with the parent operation of machining.

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**Size of the mould = (8.6 cm×7 cm×1cm)**

**Fig. 1.** Steel mould

**Fig. 2.** Sample of Graphite reinforced polymer composite

**3.1 Materials Used For Fabrication Work**

1. **Collection of Matrix material**: Matrix material select, Epoxy resin LAPOX (L-12) and HARDER K-6 as binder for the resin.
2. Reinforcement of Natural graphite.
3. Requirements for the Fabrication of Composites- Epoxy resin, Hardener and mould for making size of specimen.

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**Fig. 3.** Milling operation of graphite reinforced polymer composite

**3.2 Description of CNC machine**

CNC vertical machining centre manufactured by BHARAT FRITZ WERNER LTD.

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**3.3 Tool material –** HSS MILLING CUTTER (Diameter of milling cutter = 5mm)

**Fig. 9.** CNC vertical machining centre **Fig. 8.** HSS milling cutter

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| SI.NO | MRR  (mm3/sec) | Thrust  (N) | Torque  (N-mm) | Ra  (µm) |
| 1 | 0.6287 | 0.28 | 0.1 | 1.40 |
| 2 | 1.29385 | 0.31 | 0.18 | 0.8 |
| 3 | 2.60233 | 0.5 | 0.08 | 0.9 |
| 4 | 5.5404 | 0.36 | 0.13 | 0.9 |
| 5 | 0.826183 | 0.42 | 0.05 | 1.1 |
| 6 | 0.597195 | 0.39 | 0.11 | 0.8 |
| 7 | 5.7360 | 0.44 | 0.11 | 1.20 |
| 8 | 3.19013 | 0.39 | 0.25 | 1.1 |
| 9 | 1.17894 | 0.31 | 0.06 | 0.7 |
| 10 | 4.01136 | 0.42 | 0.16 | 0.9 |
| 11 | 0.958750 | 0.44 | 0.13 | 1.6 |
| 12 | 2.1732 | 0.28 | 0.16 | 1.50 |
| 13 | 2.8615 | 0.5 | 0.19 | 2.4 |
| 14 | 2.30162 | 0.33 | 0.13 | 1.0 |
| 15 | 1.8593 | 0.36 | 0.09 | 0.7 |
| 16 | 1.15410 | 0.25 | 0.13 | 1.4 |

**Table 3.** Experimental data (Output Response)

**4 Parametric Optimisation: Utility Theory**

The term utility means the usefulness of a procedure in orientation to the expectations levels of the customers. When doing the machining operation the number of output characteristics has been used to evaluate the performance. So, the joint amount has been essential to scale its complete performance which are used to the account of the comparative involvement of totally to the excellence features. Overall utility of the process is indicated by index of composite. Utility theory gives the procedural frame­work for the assessment of another features complete through individuals, organizations as well as groups. Basically the Utility theory mentions to the amount of satisfaction in which the each elements gives to the choice maker. Therefore, utility maximisation principal that has been used for the any type of decision. According to the utility theory the decision maker provides best possible decision. Based on the utility concept, XI is the helpfulness portion of an attribute or excellence features, there are N points to be used for assessing the consequence space. Now the combined utility function may be define as follows: Now, U (X1…. X2…… X3…….XN) = f (U1(X1), U2(X2)… UN (XN). Here, UI (XI) shows the utility of the Ith point.The total function of utility was the sum of individual utilities, if the points were self-determining as well as was given in the below: U (X1…… X2……. X3…….XN) = ∑ UIXI Where, I = 1….. 2…..3……N,The total function of utility next hiring the weights to the points may express such as:

U(X1, X2, X3…….XN) = ∑ WI.UIXI Where, I = 1, 2, 3……N

**Utility value determination:** Utility value has been evaluated based the preference scale of quality characteristic. Basically there are two random mathematical values which has referred to the preference number which lies on the 0 as well as 9. The value has been assigned to the acceptable range as well as the finest worth of the quality characteristic correspondingly. Gupta and Murthy [15-18] has been planned that the first choice (Preference number “PI “) could state in the logarithmic gauge has given below.

PI = Alog (Xi/Xi\*)

Now, the value of XI of several excellence features or characteristic I, XI was impartial satisfactory data of excellence features I as well as, A has shown as a constant [19]. The data of A may search through the state as given below. If the XI = X\* (Where X\* has been the best optimal value), Now PI = 9. So,

A = 9/log (XI/XI\*), Total function of Utility has been shown as follows: U = ∑ WiPi

Where i = 1, 2, 3……n, As for the concern to the state: ∑ Wi = 1, Where i= 1, 2, 3……n, The total index of utility that has designed for the optimisation of a single objective function. Among the different type of quality characteristics such as lower-the-better, higher-the-better as well as nominal-the-best (NB) mentioned through Taguchi technique, meaning of utility may greater. When using utility method the obtain data of single output response has been collected for computing the total index of utility. The Overall index of utility has been severed for the optimisation of unique function of objective.

**5 Result and Discussion**

The observed data for Thrust, Torque, MRR and Ra depicted in Table 3 and preference number (PI) which has been used in the utility theory. Taguchi method has applied to find optimal setting value than predicted the main data and the predicted value and overall utility is shown in the Table 4. The analysis of signal to noise ratio is shown in fig. 5.

**Table 4.** Preference number and overall utility

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| SI.NO | Pi thrust | Pi torque | Pi Mrr | Pi Ra | U overall | SNRA1 | MEAN1 | PSNRA1 | PMEAN1 |
| 1 | 7.528511 | 5.123911 | 0.204526 | 3.937015 | 4.198491 | 12.46186 | 4.198491 | 17.41107 | 6.653447 |
| 2 | 6.206939 | 1.836999 | 3.075757 | 8.024641 | 4.786084 | 13.59961 | 4.786084 |  |  |
| 3 | 0 | 6.371733 | 5.855732 | 7.164313 | 4.847945 | 13.71115 | 4.847945 |  |  |
| 4 | 4.265381 | 3.656766 | 8.861971 | 7.164313 | 5.987108 | 15.54434 | 5.987108 |  |  |
| 5 | 2.263849 | 9 | 1.291247 | 5.698546 | 4.56341 | 13.18579 | 4.56341 |  |  |
| 6 | 3.226086 | 4.590935 | 0 | 8.024641 | 3.960415 | 11.95481 | 3.960415 |  |  |
| 7 | 1.659821 | 4.590935 | 9 | 5.062985 | 5.078435 | 14.1146 | 5.078435 |  |  |
| 8 | 3.226086 | 0 | 6.665931 | 5.698546 | 3.89764 | 11.81604 | 3.89764 |  |  |
| 9 | 6.206939 | 7.980455 | 2.705749 | 9 | 6.473286 | 16.2225 | 6.473286 |  |  |
| 10 | 2.263849 | 2.495644 | 7.577234 | 7.164313 | 4.87526 | 13.75996 | 4.87526 |  |  |
| 11 | 1.659821 | 3.656766 | 1.883273 | 2.961656 | 2.540379 | 8.097971 | 2.540379 |  |  |
| 12 | 7.528511 | 2.495644 | 5.138817 | 3.433068 | 4.64901 | 13.34721 | 4.64901 |  |  |
| 13 | 0 | 1.534655 | 6.233427 | 0 | 1.94202 | 5.765076 | 1.94202 |  |  |
| 14 | 5.395159 | 3.656766 | 5.367221 | 6.394724 | 5.203467 | 14.32586 | 5.203467 |  |  |
| 15 | 4.265381 | 5.713088 | 4.5182 | 9 | 5.874167 | 15.37893 | 5.874167 |  |  |
| 16 | 9 | 3.656766 | 2.621032 | 3.937015 | 4.803703 | 13.63152 | 4.803703 |  |  |

|  |
| --- |
|  |

**Fig. 5.** Graph of Signal to Noise ratio

|  |  |  |
| --- | --- | --- |
| **Optimal setting** | | **Predicted value** |
| Speed | 500mm | S/N ratio **17.4111** |
| Feed rate | 25mm/rev. |
| Depth of cut | -1.5mm |
| Weight % | 40% |

**Table 8.** Predicted value and optimal setting

**6 Conclusion**

The present study is mainly based on the multi objective optimisation for getting the preference number and overall utility in the concept of utility theory and also used to maximised metal removal rate and minimise the thrust, torque and surface roughness. The determination of getting the most desirable parametric setting for achieving the overall performance. For optimising these problem of multi response optimisation, utility theory has been proposed and transform into multi response to single response optimisation. The various parameters in terms of accuracy and degree of influence have applied to predict and examine the modal analysis effortlessly. Therefore, the combination of optimal parameter have gained by the method of Taguchi and mentioning the criteria is higher the better to the indexes of overall utility. From the above mentioning information, it have been proven that the utility based Taguchi method has accomplished for giving the effective milling situation in direction of minimise the Thrust, Torque and Surface roughness as well as maximise the metal removal rate. This technique is ideal for the off-line process of quality control as well as useful for mass fabrication positions.

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