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Optimization of machining parameters when turning PA66-GF30% using CoCoSo method

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Abstract: The goal of manufacturers today is to lower the costs of machining operations as much as possible by reducing energy consumption and increasing productivity while ensuring good surface condition. Thermoplastic polymers are widely used in several fields of engineering because of their good properties. In the present study, a metal carbide tool was used to machine a polyamide reinforced with 30% glass fiber (PA66-GF30%) specimen in a dry environment according to the Taguchi method with nine experiments (L9). Input parameters are cutting velocity (Vc), feed rate (f) and depth of cut (ap). The corresponding output performances are surface roughness (Ra), cutting force (Fz), cutting power (Pc) and material removal rate (MRR). The results were used to perform a multi-objective optimization of the operating conditions using the MCDM method, which is the classification method based on CoCoSo coupled with the Taguchi approach. The desired objective of this study concerned the minimization of (Ra, Fz, and Pc) at the same time as maximizing (MRR). The results highlighted the performance of the studied configuration.

Keywords: Machining, PA66-GF30%, Thermoplastic polymers, optimization and CoCoSo method.

1. Introduction

Synthetic engineering polymers are frequently employed across diverse domains to substitute for numerous metals and their alloys in situations that demand a unique combination of characteristics such as light weight, mechanical strength, and specific properties that are needed [1]. In recent years, glass-fiber reinforced polymers (GFRP) have become more widespread in the engineering polymer industry due to the presence of glass fibers, and reinforced polyamide (PA66-GF30%) in particular is increasingly used in a wide range of industrial applications such as aeronautics, robotics, safety and automotive manufacturing [2]. A very few research studies on the impact of cutting parameters on the machining of PA66-GF30. Among them, **Fountas et al** [3] investigated the influence of machining parameters, namely (Vc, f, ap) on the components of cutting force during turning of PA66-GF30%, using ANOVA analysis. It was found that cutting forces decrease with an increase in (Vc) and augment with the increase in (f). **Gaitonde et al** [4] conducted an experimental study on machining PA66-GF30% with a metal carbide tool (K10) using Taguchi's method to obtain the optimal cutting regimes of responses (Pc and Ks) individually. Multi-criteria decision-making (MCDM) methodologies are extensively used by researchers in several areas of study for optimization purposes. The efficacy of MCDM approaches in finding the most favorable machining conditions has been established [5].

This paper presents a new MCDM method incorporating the Combined Compromise Solution method. Many other industries have found success with the CoCoSo technique, proving its versatility and usefulness. As a decision-making aid, it offers a structured method for evaluating alternatives [6]. Various studies have applied this method in different industrial sectors in

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order to make a decision regarding the choice of an optimal cutting regime according to the desired criteria.

2. Experimental Procedures

The polymer specimen cylindrical bar chosen in this study is composite polyamide reinforced with 30% glass fibers (PA66-GF30%). The experiment tests are carried out on the conventional lathe, SN40C model. The cutting tool used is SPGR120308, which is fixed in a SDPN2525M12 tool holder. The measurements of cutting forces and surface roughness were obtained directly using a Kistler dynamometer (9257B) and a Mitutoyo roughness tester (2D) type (SJ-210), respectively. Additionally, Pc and MRR were calculated by Eqs. (1) and (2), respectively. Figure 1 depicts the experimental setup utilized in this work.

$$Pc(W) = \frac{1}{60}\left(Fz(N) \times Vc\left(\frac{m}{min}\right)\right) \quad (1)$$

$$MRR\left(\frac{cm^3}{min}\right) = Vc\left(\frac{m}{min}\right) \times f\left(\frac{mm}{rev}\right) \times ap(mm) \quad (2)$$

The experiments were established through Taguchi L9 (3^3) orthogonal array to identify the effect of three

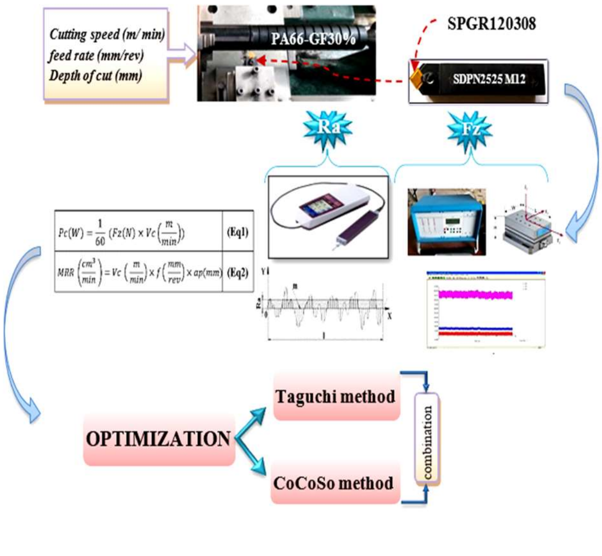

Fig. 1 Experimental setup diagram

factors with three levels, cutting villosity (80, 115 and 206) m/min, feed rate (0.08, 0.12 and 0.16) mm/rev and depth of cut (0.5, 1 and 2) mm. the experimental layout plan and corresponding responses values are shown in Table 1.

Tabel 1 Experimental layout plan and corresponding responses values

N	*Input factor*			*Output parameters*			
	Vc (m/min)	f (mm/rev)	ap (mm)	Ra (µm)	Fz (N)	Pc (W)	MRR (cm^3/min)
1	80	0.08	0.5	1.4	16.48	21.97	3.20
2	80	0.12	1	1.69	33.92	45.23	9.60
3	80	0.16	2	2.07	65.76	87.68	25.60
4	115	0.08	1	1.41	30.62	58.69	9.20
5	115	0.12	2	1.56	58.06	111.28	27.60
6	115	0.16	0.5	1.78	26.66	51.10	9.20
7	206	0.08	2	1.24	35.37	121.44	32.96
8	206	0.12	0.5	1.27	20.18	69.29	12.36
9	206	0.16	1	1.56	35.54	122.02	32.96

3. Results and Discussion

3.1. Optimization of Cutting Conditions

The optimization of cutting parameters is an important step in the machining process, which has been the subject of several research works using different techniques [7]. It makes it possible to choose the optimal cutting conditions in order to satisfy the desired objective. This has a direct impact on productivity, quality and the total cost of machining.

3.1.1 Optimization mono-objectif (Taguchi):

Taguchi's mono-objectif optimization method is based on the signal-to-noise (S/N) ratio which is used to analyze the experiment results. such that (S) is the signal factor that indicates the true value of the system and (N) is the noise factor that represents the factor not included in the experiment design. The ratio (S/N) results are calculated by equations (3 and 4) according to the desired objectives, "the smaller-the better" for the minimization of Ra, Fz, and Pc, and "the larger-the better" for the maximization of MRR respectively.

$$\frac{S}{N} = -10\ log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \quad (3)$$

$$\frac{S}{N} = -10\ log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} \frac{1}{y_i^2}\right) \quad (4)$$

3.1.2 Optimization multi-objectif (CoCoSo Method):

The CoCoSo approach, a brand-new MCDM technique that Yazdani created in 2019 [6], relies on combining the use of WSM and WPM to find a compromise solution to a particular problem. The best option is the one with the highest solution value. This method is executed according to the steps shown in Figure 2.

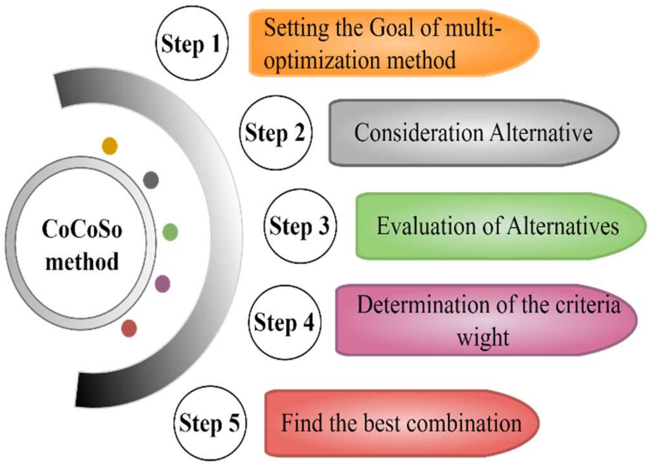

Fig.2 CoCoSo method chart

The CoCoSo method procedural steps are enumerated as below:

Step 1: Definition of the objectives

Step 2: development of the initial decision matrix (A)

The corresponding decision matrix is first formulated considering m alternatives and n criteria.

$$A = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}$$

Step 3: normalization of the decision matrix

- For maximization:

$$r_{ij} = \frac{x_{ij} - \min x_{ij}}{\max x_{ij} - \min x_{ij}} \quad (5)$$

(i=1,….,m ; j=1,…,n)

Step 4: Using the WSM and WPM methods to calculate the Si and Pi values of each parameter

$$\boldsymbol{S_i} = \sum_{j=1}^{n} r_{ij} * W_j \quad (6)$$

$$\boldsymbol{P_i} = \sum_{j=1}^{n} (r_{ij})\,\hat{}\,W_j \quad (7)$$

Step 5: Calculates scoring strategies for the re lative weights of each alternative, they are generated using aggregation strategies:

- Arithmetic average of WSM sums and WPM products:

$$\boldsymbol{K_{ia}} = \frac{P_i+S_i}{\sum_{i=1}^{n} (P_i+S_i)} \quad (8)$$

- Sum of WSM and WPM relative scores:

$$\boldsymbol{K_{ib}} = \frac{S_i}{\min S_i} + \frac{P_i}{\min P_i} \quad (9)$$

- Alternative Performance Scores K_{ic} :

$$\boldsymbol{K_{ic}} = \frac{\lambda S_i+(1-\lambda)P_i}{\lambda \min S_i+(1-\lambda) \max P_i} \quad (10)$$

The highest performance score is desirable; note that λ can range between 0 and 1 but is usually λ equal to 0.5.

Step 4: Calculation of the final approximation score of the alternatives; note that the greatest alternative is regarded as the best option for the final selection.

$$\mathbf{K_i} = (K_{ia} \times K_{ib} \times K_{ic})^{1/3} + \frac{1}{3}(K_{ia} + K_{ib} + K_{ic}) \quad (11)$$

From the results of the Taguchi method based on the S/N ratio, the values of the normalized decision matrix and the Ki index of each experiment were calculated using equations 5 to 11, and their values are recorded in **Table 2.**

Table 2 Normalization values and Ki index of each experiment

N°	NORMALIZATION				K_i	Rank
	Ra	Fz	Pc	MRR		
1	0.764	1.000	1.000	0.000	2.521	2
2	0.396	0.478	0.579	0.471	2.350	5
3	0.000	0.000	0.193	0.892	1.214	9
4	0.751	0.552	0.427	0.453	2.504	3
5	0.553	0.090	0.054	0.923	2.012	8
6	0.294	0.652	0.508	0.453	2.332	6
7	1.000	0.448	0.003	1.000	2.442	4
8	0.953	0.854	0.330	0.560	2.802	1
9	0.553	0.445	0.000	1.000	2.082	7

According to the decreasing ranking of the Ki values in **Table 2**, Experiment 8 has the greatest K_i index value (2.802), indicating that it is the optimal solution among all options. The results of the analysis of this optimization case, which is concerned with the minimization of (Ra, Fz, and Pc) and maximization of (MRR) simultaneously, yield the following ideal regime: $Vc_3\ f_2\ ap_1$.

To conclude, we can say that for this optimization case the CoCoSo method focuses on minimizing surface roughness, cutting force and energy consumption. As for productivity, the value takes half (½) of the maximum value (32.96 cm^3/min).

4. Conclusions

The present experimental study, which focused on optimization during dry machining of polyamide PA66-GF30% during turning using a metal carbide cutting tool, leads to the following conclusions:

- Multi-objective optimization by the method CoCoSo was successfully applied. The optimal regime found is the following: Vc= 206 (m/min), f= 0.12 (mm/rev) et ap= 0.5 (mm); Ra= 1.27 (µm), *Fz* = 20.18 (N), *Pc* = 69.285 (W), and *MRR* = 12.36 (cm^3/min).

- The CoCoSo method is easy to use and easy to calculate. It is used to make decisions based on more than one factor.

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