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Grey Relational Analysis on CO_2 Laser Cutting Quality of Nano Clay Composites Polymers

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Abstract

Laser beam cutting of polymers seems to be a superior tool to any cutting methods duehigh material utilization and production flexibility, precise cuts with narrow kerf width, faster cutting process, better accuracy and high cut edge quality .Moreover, no tool wear or tool change.

This paper presents a brief review of work done by some researchers based on laser cutting process for parametric optimization using different techniques. Sixteen Experimental tests are arranged according to Taguchi method. The influence of laser cutting parameters on the cut quality is studied for two types of nanoclay composites polymers (HDPE and PP). Moreover, a comparison between PP and HDPE nanoclay composites polymers has been done based on grey relational analysis for laser cut quality .The results are analyzed to assess the optimum cutting conditions for each polymer.

Keywords:HDPE, PP, Nanoclay composites, Greyrelational analysis, ANOVA, Laser cut ,MRR, KW, HAZ , Dross.

I. INTRODUCTION

Polymers are rapidly growth nowadays in biomedical, optics, vehicles, and electronics industries due to of their good chemical and physical properties, besides easy of processing, weight saving and low costs . Polymer nanoclay composites are a relatively new class of nano scale materials. Furthermore; these polymers have some problems especially in cutting with traditional and nontraditional cutting techniques.

Several works have been made to study the performance characteristics of cutting polymers by laser beam using different design of experiments as follows:

Neimeyer et al. [1] presented an experimental program based on a factorial design to provide and understanding the relationship between CO_2laser cutting parameters and cut surface quality.Mathew et al. [2] developed a second order responsesurface model for determination the output cutting parameters as a function of input cutting parameter during pulsed Nd-YAG laser cutting.

M.M.Noor et al. [3] illustrated the effect of laser cutting parameter on the surface roughness during the cutting of acrylic by pulsed CO_2 laser beam. Moreover, Box-Behnken design based on response surface method (RSM) was used to minimize the number of experiments and to develop the first and second order regression equation.

Choudhurya and Shirley [4] explained the cutting of three polymeric materials by CO_2 laser. Twelve sets of tests were carried out for each polymer based on the central composite design. Predictive models have been developed by response surface methodology (RSM).

Ayob et al. [5] studied the influences of carbon nanotubes on laser cutting of multi-walled carbon nanotubes/poly methyl methacrylate (MWCNT/PMMA) composite. Design of experiments was performed using full factorial method. Experiments analysis is performed using analysis of variance method. Milos M. et al. [6] demonstrated the application of Taguchi method to optimize surface roughness in CO_2 laser cutting. The experiment was designed and carried out on the basis of standard L25 Taguchi's orthogonal array. Moreover it was using the ANOVA analysis to determine the contribution of each control parameter on the cutting quality characteristics.

T. A. El-Taweel et al [7] studied the cutting performance of a CO_2 laser on Kevlar-49 composite materials. Taguchi technique is employed to identify the effect of laser control parameters on the quality of cut parameters. Analysis of variance (ANOVA) and signal-to-noise (S/N) ratio response is used to determine the significant parameters and the optimal combination levels of cutting parameters. Also mathematical model was developed to evaluate the relationship of laser cutting parameters with the quality of cut parameters. For instance, due to limitation of single-objective optimization of Taguchi method, Dubey and Yadava [8] explained the principal component analysis with orthogonal array to determine the multi-objective optimization of Nd: YAG laser cutting of nickel-based super alloy sheet. In a different study, Pandey and Dubey [9] combined Taguchi method with fuzzy logic theory to optimize multiple responses. The set of optimized parameters were determined based on the highest fuzzy multi-response performance index.

Although RSM showed some success in formulating the mathematical relationships between multiple input and optimized response variables using a sequence of designed experiments the problem becomes more complicated and challenging if more output parameters are considered with higher number of samples.

Additionally, multi-objective optimization techniques have proved useful for determining the optimized set of process parameters by taking into consideration all measured cutting characteristics.

Grey relational analysis (GRA), as a discrete statistical analysis was proposed by Deng [10], to optimize process parameters based on multiple laser cut quality characteristics of different thermoplastics is employed. Ming-Jong Tsai & Chen-Hai Li [11] applied the grey relational analysis (GRA) directly optimized‖ laser cutting of a (QFN) strip using six performance characteristics. They have taken nine experiments based on orthogonal array of L9. In this paper, also ANOVA is employed to determine the contribution of each control parameter on the cutting quality characteristics. Compared with the Taguchi optimization method, the GRA approach is significantly simpler because it directly assigns appropriate weighting factors to the required qualities.

Chen et al. [12] employed Grey relational analysis to optimize CO_2 laser cutting of PMMA. K.F. Tamrin et al [13] applied the grey relational analysis (GRA) to determine a single optimized set of input cutting parameters based on the highest relational grade for cutting three different polymers by CO_2 laser beam. S. Nagesh1et al. [14] studied the effect of two types of nano fillers on laser cutting of vinylester/glass nanocomposites. Designs of experiments are performed using orthogonal array technique. Experiments analyses are performed using grey relational analysis method.

A.M. Abdel Maboud et al. [15] presented an experimental study into the influence of the laser beam cutting parameters on the surface quality for HDPE nanoclay composites polymer. Experiments are carried out according to

Taguchi method and the results are explained according to grey relational method .Best cutting conditions are determined. Results revealed that the beneficial effect of adding nanoclay composites into HDPE polymer.

II. EXPERIMENTAL WORK

All experimental tests were performed on high density polyethylene (HDPE) and Polypropylene (PP) polymers with nanoclay composite materials andfabricated in the sheet form of 3mm thickness. These polymeric materials are widely used in medical and biotech devices (e.g. for catheters, meshes, filters, membranes, micro channels) and in the microelectronic and sensor industries for insulating layers in multi-level devices. In all these cases, the high precision required has to be matched to high quality (i.e. lack of damage and burrs, no melting, high reproducibility). Other high precision uses of polymers include their use as deposition masks for the production of high-resolution features such as micro-electrodes.

Cutting these polymers with traditional methods has some limitations due to wear and tear caused by sharp cutting tools. Also, due to high heat generated during cutting, which causing high tool wear and poor surface quality. Moreover, cutting polymers with some nontraditional machining methods, like electrochemical, electro discharge, ultrasonic, and water jet cutting have some constraints due to non-conductivity of polymers and high absorption of cutting energy.

The engineering polymers High Density Polyethylene (HDPE) and Polypropylene (PP) are used for preparation of nanocomposites material. Nanoclay of (25-30 wt. % methyl dihydroxyethyl hydrogenated tallow ammonium chloride) was used. The polymers and nanoclay materials are mixed by melt blending technique in a bra bender plastic order lab station mixer attached with PL-2000 controller unit. The content of nanoclay was 0, 1, 3and 5by weight %. In order to produce nanocomposites material (test specimens) sheets, plastic mold with dimension of 175x80x3 mm is used [15].

Three tests were performed on the specimens to assess their chemical and physical stability [15]. They are:

1- Thermo-gravimetric analysis (TGA).
2- Dynamic mechanical thermal analysis (DMTA).
3- Shore D hardness test.

All laser cutting experiments were carried out using laser machine consisting of a 130W pulsed CO_2 laser (sharp laser cutting machine model CF90) and a two axes CNC-controlled table with work volume 1x1 m [15].The quality characteristics of cutting surface in LBC involves four items, kerf width (KW), heat affected zone (HAZ), dross inclusion and metal removal rate (MRR) .The kerf width and heat affected zone measurements were done by used computerized optical microscope of different magnifications Model Nemesis 9500 in the image plane.While, the simplest and accurate method for measuring the dross is by using the digital micrometer, type Starrett, Model No. 734[15]**.** To determine the amount metal removal workpieces are weighted before and after cutting using sensitive balanced with an accuracy of 0.0001g.

III. EXPERIMENTAL METHODOLOGY

The 16 experimental runs have been done with three input parameters and four levels for each as listed in Table 1.The number of experiments are determined according to Taguchi method [15].The 16 experiments and their actual values are reported in Table2.

TABLE 1
CUTTING VARIABLES AND THEIR LEVELS

Factors		Level 1	Level 2	Level 3	Level 4
P	Laser Power (W)	72	84	102	120
S	Cutting speed (mm/sec)	2	4	6	7
N	Ratio of nanoclay %	0%	1%	3%	5%

TABLE 2
16 TEST CONDITIONS

	Factors		
	P	S	N
No	Laser Power (W)	Cutting Speed (mm/sec)	Ratio of nanoclay %
1	72	2	0
2	72	4	1
3	72	6	3
4	72	7	5
5	84	2	1
6	84	4	0
7	84	6	5
8	84	7	3
9	102	2	3
10	102	4	5
11	102	6	0
12	102	7	1
13	120	2	5
14	120	4	3
15	120	6	1
16	120	7	0

Grey relational analysis is used for optimization of multi performance characteristics. In grey relational analysis, experimental data i.e. measured features of quality characteristics of the product are first normalized ranging from zero to one. This process is known as grey relational generation. Next, based on normalized experimental data, grey relational coefficient is calculated to represent the correlation between the desired and actual experimental data. Then overall grey relational grade is determined by averaging the grey relational coefficient corresponding to selected responses. The overall performance characteristic of the multiple response process depends on the calculated grey relational grade. This approach converts a multiple response process optimization problem into a single response optimization situation, with the objective function is overall grey relational grade. The optimal parametric combination is then evaluated by maximizing the overall grey relational grade [10, 12, 16-21].

IV. RESULTS AND DISSUASION

The thermal analysis of nanoclay composites polymers showed an improving in TGA, DMTA and hardness tests as follows:
For HDPE nanoclay composites polymer the TGA test indicated that at 5 % nanoclay ratio, the thermal stability against degradation was improved by 2.83 % and the degradation temperature at 50 % of mass loss was increased by 2.5 %. Moreover, for DMTA test at 5 %. nanoclay ratio, the amount of retention polymer chains for energy was increased at room temperature by 48.15 %. Furthermore, Shore D hardness was increased by 15.4% which indicates that the hardness increases as nanoclay ratio increases.

While For PP nanoclay composites polymer the TGA test showed that at 5 %. nanoclay ratio, the thermal stability against degradation was improved by 3.14 % and the degradation temperature at 50 % of mass loss was increased by 7.02 %. Also, for DMTA test at 5 % nanoclay ratio, the amount of retention polymer chains for energy was increased at room temperature by 46.15 %. While Shore D hardness was increased by 4.4% which indicates that the hardness has a little effect as nanoclay ratio increases.

Table 3 listed the experimental results for output response parameters (MRR, KW, HAZ and Dross) for PP and HDPE nanoclay composites polymers.

A. *ANOVA Analysis*

The percentage contributions of each process parameter into total variation for HDPE and PP nanoclay composites polymers are shown in Figs1-4,which indicating their degree of influence on metal removal rate, kerf width, heat affected zone and dross respectively.

From Fig.1 one can noticed that cutting speed is the most dominant effect in the metal removal rate than laser power and nanoclay ratio for both HDPE and PP nanoclay composites polymers.

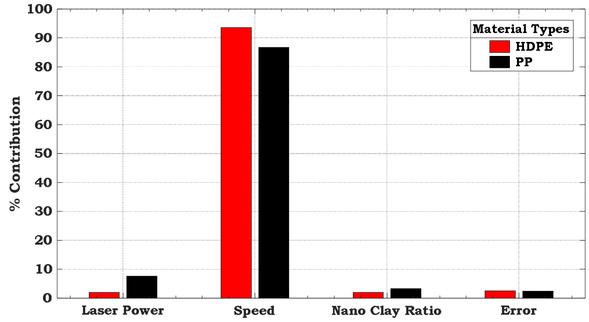

Fig.1 Effect of different laser process parameters on MRR

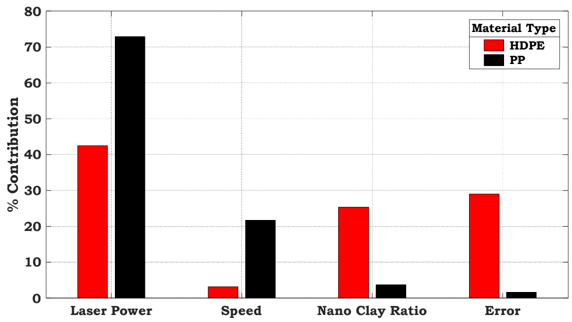

Fig.2 Effect of different laser process parameters on KW

Fig.2 shows that laser power is the most significant factor affecting the kerf width of PP nanoclay composites polymer, followed by the effect of cutting speed. For the HDPE nanoclay composites polymer, laser power and nanoclay ratio are statistically significant where the influence of laser power is about 17% greater than nanoclay ratio.

According to ANOVA results of heat affected zone as shown in Fig.3, illustrates that the nanoclay ratio is the most significant factor affecting heat affected zone of both HDPE and PP nanoclay composites polymers, followed by laser power and cutting speed.

For the case of HDPE nanoclay composites polymer as shown in Fig.4, nanoclay ratio and cutting speed are statistically significant in dross, where, the influence of nanoclay ratio is about 8% greater than cutting speed. Moreover, the cutting speed is the most significant factor that affects in the dross of PP nanoclay composites polymer, followed by effect of nanoclay ratio.

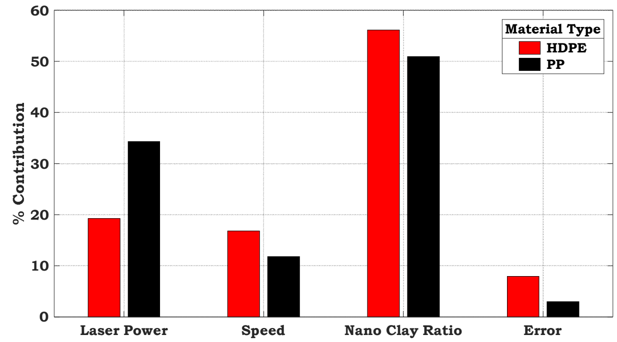

Fig.3 Effect of different laser process parameters on HAZ

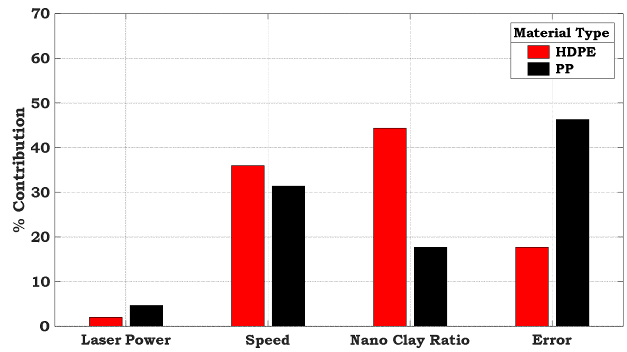

Fig.4 Effect of different laser process parameters on Dross

B. *Single Objective Optimization*

1) *Effect of Cutting Parameters on Mean Metal Removal Rate*

The relationships between input parameters and metal removal rate for HDPE and PP nanoclay composites polymers are presented in Figs. 5-7.

Fig 5 indicates that the maximum metal removal rate for the HDPE and PP nanoclay composites polymer was obtained by setting the laser power at 120 W. Furthermore, the mean metal removal rate of HDPE nanoclay composites polymer increased by about 26 % than PP nanoclay composites polymer.

The same trend is noticed in Fig.6.which indicates that the maximum metal removal rate in both types of polymers was obtained at high cutting speed of 7 mm/s. Furthermore, the mean metal removal rate of HDPE nanoclay composites polymer increased by about 39.5 % than PP nanoclay composites polymer.

The effect of nanoclay ratio on metal removal rate however is not straightforward, as shown in Fig.7. The maximum metal removal rate for the HDPE nanoclay composites polymer was obtained by additive 5% nanoclay ratio. On the contrary, the maximum metal removal rate for the PP nanoclay composites polymer was obtained by using raw polypropylene without any additions of nanoclay material.

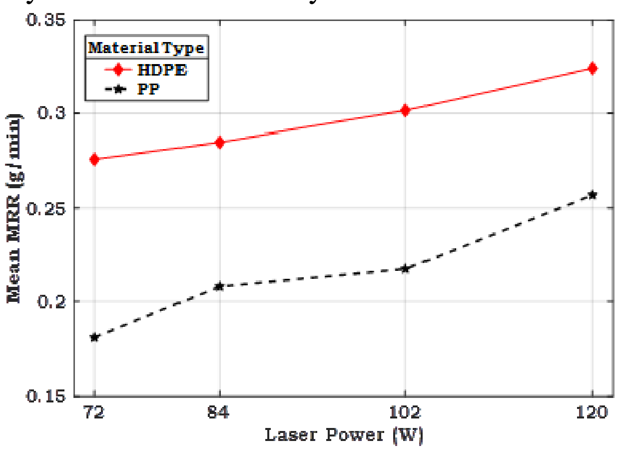

Fig.5 Effect of laser power on metal removal rate

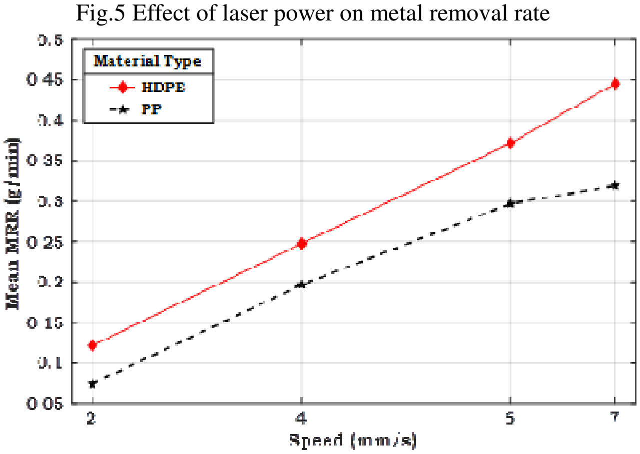

Fig.6 Effect of cutting speed on metal removal rate

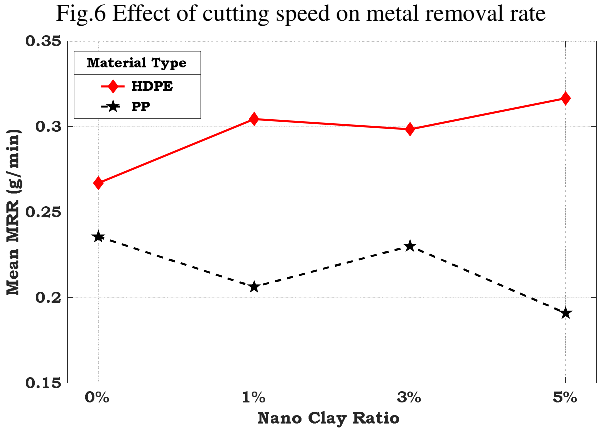

Fig.7 Effect of nanoclay ratio on metal removal rate

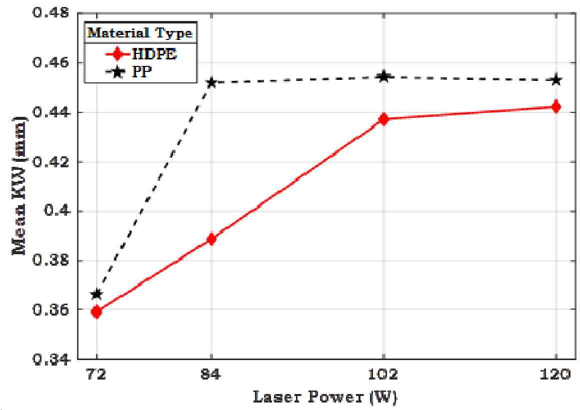

Fig.8 Effect of laser power on kerf width

2) Effect of Cutting Parameters on Mean Kerf Width

The relationships between each process variables and kerf width for HDPE and PP nanoclay composites polymers are presented in Figs.8-10. Fig.8 indicates that the minimum kerf width value for both HDPE and PP nanoclay composites polymers was obtained by setting the laser power at 72 W. Furthermore, the mean kerf width of PP nanoclay composites polymer increased by about 2 % than HDPE nanoclay composites polymer. It is noticed from Fig.9 that the minimum kerf width value in both types of polymers was obtained at laser cutting speed of 6 mm/s. Furthermore, the mean kerf width of PP nanoclay composites polymer increased by about 2.67 % than HDPE nanoclay composites polymer.

The effects of nanoclay ratio on kerf width is not straightforward, as shown in Fig.10 .The minimum values ofkerf width in both types of polymers are obtained by additive of 5% nanoclay material. Furthermore, the mean kerf width of PP nanoclay composites polymer increased by about 14 % than HDPE nanoclay composites polymer.

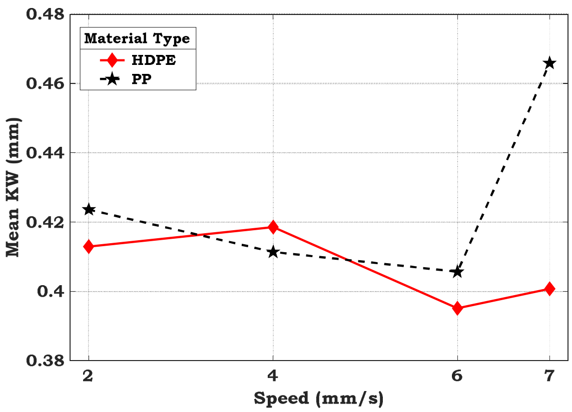

Fig.9 Effect of cutting speed on kerf width

3) Effect of Cutting Parameters on Mean Heat Affected Zone

Fig.11 illustrates the relation between heat affected zone and laser power for HDPE nanoclay composites polymer. The minimize value of heat affected zone was obtained at low laser power 72 W. Moreover, the relation between heat affected zone and laser power for PP nanoclay composites polymer is not straightforward and the minimum value of heat affected zone was noticed at laser power 102 W.

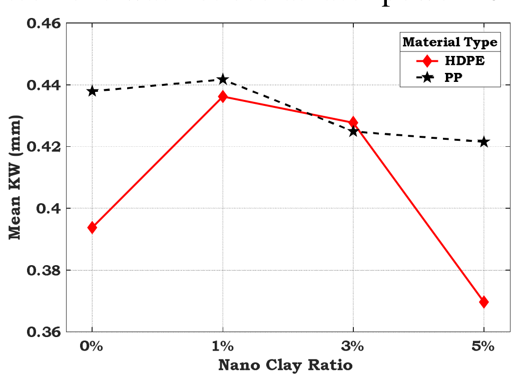

Fig.10 Effect of nanoclay ratio on kerf width

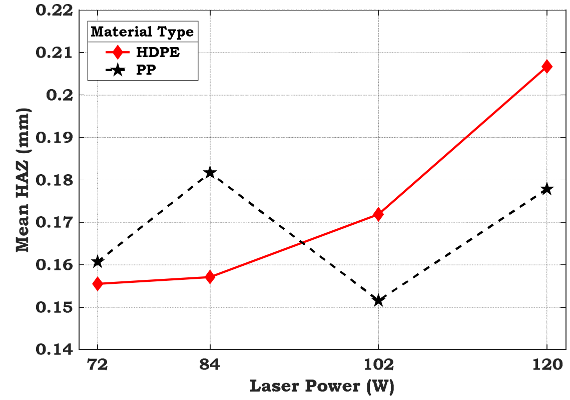

Fig.11 Effect of laser power on heat affected zone.

Fig.12 indicates that the minimum value of heat affected zone for both HDPE and PP nanoclay composites polymers was obtained by setting the cutting speed at 7 mm/s and 6 mm/s. respectively.

Fig.13 illustrates the influence of nanoclay ratio on heat affected zone. The minimum value of heat affected zone in both types of polymers was obtained by using the raw HDPE and PP polymers without any additions of nanoclay materials. Furthermore, the mean heat affected zone of PP nanoclay composites polymer increased by about 12% than HDPE nanoclay composites polymer.

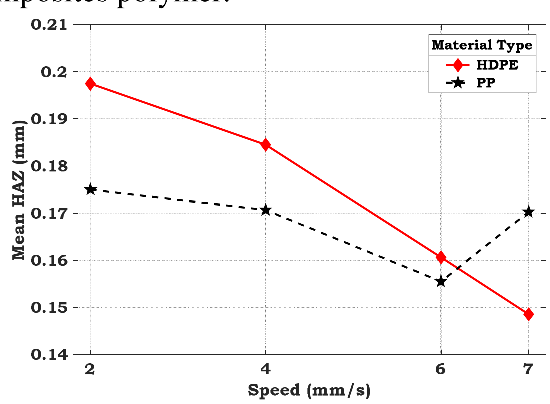

Fig.12 Effect of cutting speed on heat affected zone.

4) Effect of cutting parameters on mean dross

The relations between each process parameter and dross value for HDPE and PP nanoclay composites polymers are presented in Figs. 14-16.

The effect of laser power on dross is not straightforward, as shown in Fig.14 .The minimum value of dross for HDPE nanoclay composites polymer was obtained at laser power of 120 W followed by 84 W. However, the minimum value of dross for PP nanoclay composites polymer was obtained by setting the laser power at 84 W.

Fig.15 shows that the minimum value of dross for HDPE nanoclay composites polymer was obtained by setting the cutting speed at 4 mm/s. Moreover, the minimum value of dross for PP nanoclay composites polymer was obtained at cutting speed of 6 mm/s.

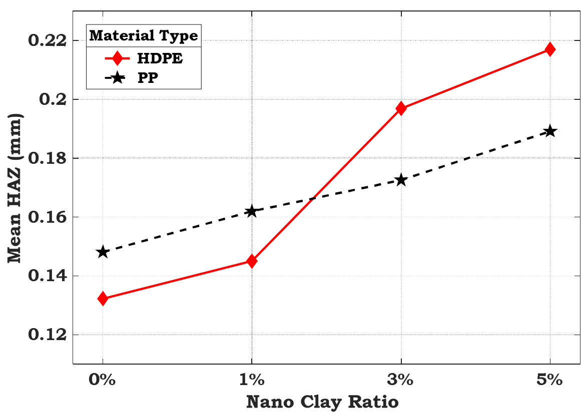

Fig.13 Effect of nanoclay ratio on heat affected zone.

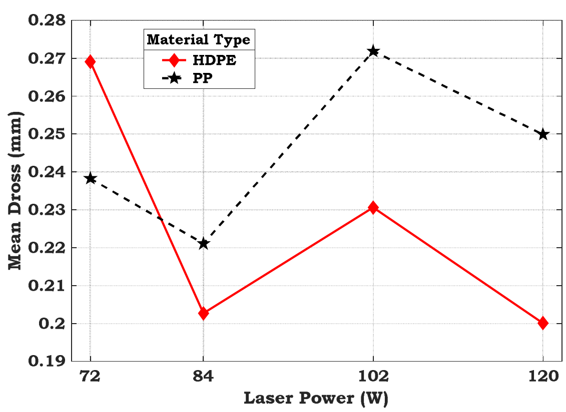

Fig.14 Effect of laser power on dross

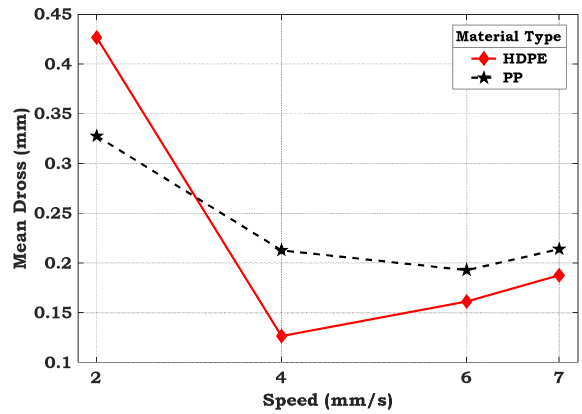

Fig.15 Effect of cutting speed on dross

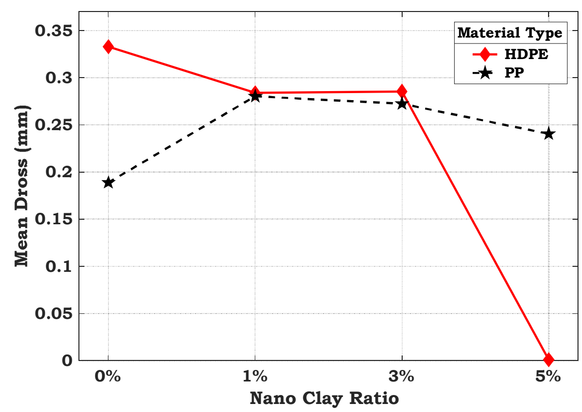

Fig.16 Effect of nanoclay ratio on dross

Fig.16 indicates the variation of dross value against nanoclay ratio. The minimum value of dross for HDPE nanoclay composites polymer was obtained at 5% nanoclay ratio. On the contrary, the minimum value of dross for PP nanoclay composites polymer was obtained by using raw PP without any additions of nanoclay material

TABLE 3
EXPERIMENTAL RESULTS FOR OUTPUT PARAMETERS

	Experimental Results							
	MRR (g/min)		KW (mm)		HAZ (mm)		Dross (mm)	
Exp.	HDPE	PP	HDPE	PP	HDPE	PP	HDPE	PP
1	0.0840	0.0605	0.4059	0.3663	0.1432	0.1520	0.6990	0.3270
2	0.2160	0.1532	0.3648	0.3608	0.1363	0.1567	0.1378	0.1735
3	0.3480	0.2333	0.3412	0.3487	0.1701	0.1480	0.2385	0.3120
4	0.4560	0.2752	0.3249	0.3896	0.1724	0.1861	0.001	0.1405
5	0.1080	0.0708	0.4018	0.4575	0.1537	0.1855	0.5328	0.3010
6	0.2220	0.1920	0.3915	0.4295	0.1281	0.1584	0.1083	0.1733
7	0.3480	0.2500	0.3532	0.4311	0.1939	0.1952	0.001	0.1360
8	0.4620	0.3188	0.4084	0.4903	0.1527	0.1875	0.1685	0.2740
9	0.1260	0.0822	0.4425	0.4374	0.2017	0.1637	0.4745	0.3173
10	0.2940	0.1551	0.3990	0.4321	0.2105	0.1764	0.001	0.3190
11	0.3420	0.3193	0.4075	0.4602	0.1319	0.1204	0.1943	0.1318
12	0.4440	0.3128	0.4995	0.4880	0.1434	0.1458	0.2525	0.3193
13	0.1680	0.0831	0.4015	0.4332	0.2912	0.1989	0.001	0.3655
14	0.2580	0.2859	0.5189	0.4232	0.2632	0.1911	0.2595	0.1853
15	0.4500	0.2880	0.4786	0.4606	0.1466	0.1598	0.2112	0.3265
16	0.4200	0.3705	0.3703	0.4956	0.1258	0.1616	0.3287	0.1223

C. Multiple Response Optimization

Grey method serves as an effective method to determine the best multiple objective optimization for several thermoplastics. It can be envisaged that ANOVA and single objective optimization have some limitations when dealing with a sizeable number of different thermoplastics with multiple cut characteristics [13].

1) Normalization of Experimental Results

Data pre-processing is a process of transferring the original sequence to a comparable sequence. For this purpose, the experimental results are normalized in the range between zero and one. The normalization can be done from three different approaches If the target value of original sequence is infinite, then it has a characteristic of 'higher-the-better' and it has a characteristic of 'lower-the-better'.

The normalization, x_{ij} for the 'higher-the-better' quality characteristic is expressed as:

$$x_{ij} = \frac{y_{ij} - \min_j y_{ij}}{\max_j y_{ij} - \min_j y_{ij}} \quad (1)$$

The normalization, x_{ij} for the 'lower-the-better' quality characteristic is expressed as:

$$x_{ij} = \frac{\max_j y_{ij} - y_{ij}}{\max_j y_{ij} - \min_j y_{ij}} \quad (2)$$

Where,:
x_{ij} is the value after data pre-processing,
y_{ij} is the response value for particular experiment number
$Max_j y_{ij}$ is the largest value of (y_{ij}).
$min_j y_{ij}$ is the smallest value of (y_{ij}).
Table 4 presents the optimization of quality characteristic needed for each response

TABLE 4
QUALITY CHARACTERISTIC OF THE MACHINING PERFORMANCE

Machining characteristic	Quality characteristic
Metal removal rate (MRR)	'higher-the-better'
Kerf width (KW)	'lower-the-better'
Heat affected zone (HAZ)	'lower-the-better'
Dross	'lower-the-better'

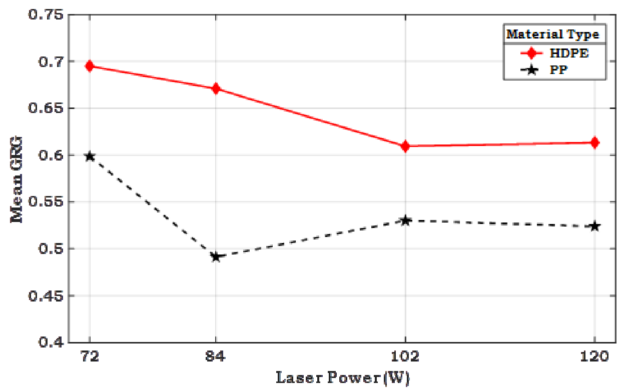

Fig.17 Grey relational grades v/s laser power

Table 5 listed the Normalization of experimental results for both PP and HDPE nanoclay composites polymers responses.

2) *Grey Relational Coefficient $\xi_i(k)$*

A grey relational coefficient is calculated to express the relationship between the ideal and actual normalized experimental results. The Grey relational coefficient $\xi_I(K)$ is expressed as:

$$\xi_i(k) = \frac{\Delta_{min}+\zeta.\Delta_{max}}{\Delta_{0i}(k)+\zeta.\Delta_{max}} (3)$$

Where:

Δ_{max} is the hieghest value of $\Delta_{0i}(k)$

Δ_{min} is the smallest value of $\Delta_{0i}(k)$

ζ is the distinguishing or identification coefficient: $\zeta \in [0, 1]$. $\zeta = 0.5$ is generally used

Table 6 listed the Grey relational coefficients $\xi_I(K)$ for both PP and HDPE nanoclay composites polymers responses.

3) *Grey Relational Grade.*

The grey relational grade is defined as follows:

$$\gamma_j = \frac{1}{m}\sum_{i=1}^{m} w_i * \xi_{ij} (4)$$

Where,
m is the number of response,
w_i is the weighting factor for the ith quality characteristic
ξ_{ij} isthe grey relational coefficient for each response.

Table 7 reported the Grey relational grade at equal weighting factor for both PP and HDPE nanoclay composites polymers responses.
The relations between each process parameter and the overall cut characteristics in terms of mean grey relationalgrades are presented in Figs.17-19 simplifying the complexity of interpreting the effect of each process parameter on multiple cut characteristics for both types of nanoclay composites polymers.
From Fig.17 the optimized cut can be achieved at low laser power. The cut quality of HDPE and PP nanoclay composites polymers decreases with the increase of laser power. Furthermore, the mean grey relational grade of HDPE nanoclay composites polymer increased by about 16% than PP nanoclay composites polymer. On the contrary, the trend reverses with respect to the cutting speed as shown in Fig.18 where the cut quality is optimized at high cutting speed of 7 mm/s [13].

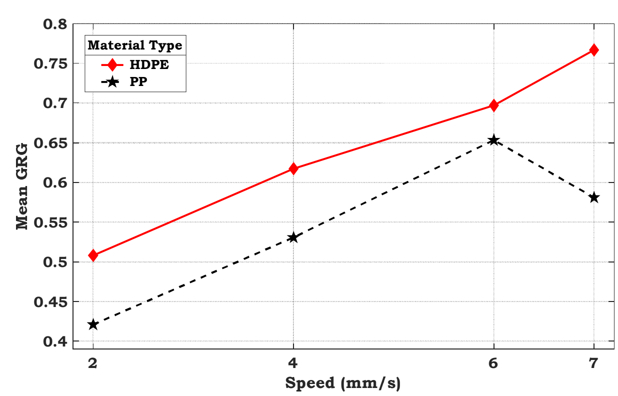

Fig.18 Grey relational grade v/s cutting speeds

TABLE 5
NORMALIZATION OF EXPERIMENTAL RESULTS

Exp.	Grey Relational Generation (Data Pre-Processing) MRR (Higher-The-Better)		KW (Lower-The-Better)		HAZ (Lower-The-Better)		Dross (Lower-The-Better)	
	HDPE	PP	HDPE	PP	HDPE	PP	HDPE	PP
1	0	0	0.5825	0.8802	0.8948	0.5975	0	0.1583
2	0.3492	0.2990	0.7943	0.9176	0.9365	0.5376	0.8040	0.7895
3	0.6984	0.5574	0.9160	1.0000	0.7322	0.6484	0.6597	0.2200
4	0.9841	0.6926	1.0000	0.7216	0.7183	0.1631	1.0000	0.9252
5	0.0635	0.0332	0.6036	0.2594	0.8313	0.1707	0.2381	0.2652
6	0.3651	0.4242	0.6567	0.4500	0.9861	0.5159	0.8463	0.7903
7	0.6984	0.6113	0.8541	0.4391	0.5883	0.0471	1.0000	0.9437
8	1.0000	0.8332	0.5696	0.0361	0.8374	0.1452	0.7600	0.3762
9	0.1111	0.0700	0.3938	0.3962	0.5411	0.4484	0.3216	0.1982
10	0.5556	0.3052	0.6180	0.4323	0.4879	0.2866	1.0000	0.1912
11	0.6825	0.8348	0.5742	0.2410	0.9631	1.0000	0.7231	0.9609
12	0.9524	0.8139	0.1000	0.0517	0.8936	0.6764	0.6397	0.1900
13	0.2222	0.0729	0.6052	0.4248	0	0	1.0000	0
14	0.4603	0.7271	0	0.4929	0.1693	0.0994	0.6297	0.7410
15	0.9683	0.7339	0.2077	0.2383	0.8742	0.4981	0.6989	0.1604
16	0.8889	1.0000	0.7660	0	1.0000	0.4752	0.5305	1.0000

The effect of nanoclay ratio on cut quality however is not straightforward, as shown in Fig.19. With the increase of nanoclay ratio, the cut quality of HDPE decreases from 0% to 3% and increases afterwards. In the case of PP, the cut quality drops from 0% to 1%, and increases up to 3% and decrease thereafter.

4) Best Level of Laser Cutting Parameters

To find out the best level of laser cutting parameters in both types of nanoclay composites polymers, the mean grey relational grade for each factor must be estimated. The calculated average grey relational grade for each factor level is shown in Table 8.The higher mean value of grey relational grade indicates the optimum level.

From Table8, one can notice that the optimum parameter levels for HDPE nanoclay composites polymers are: Laser power is 0.6951 (level 1), cutting speed is 0.7667 (level 4) and nanoclay ratio is 0.7143 (level 4). Subsequently the higher grey relational grade from each level of factor indicates the optimum level. It is concluded that the optimum parameter level for laser power, cutting speed and nanoclay Ratio is level 1 (72 W), level 4 (7 mm/s), and level 4 (5%) respectively.

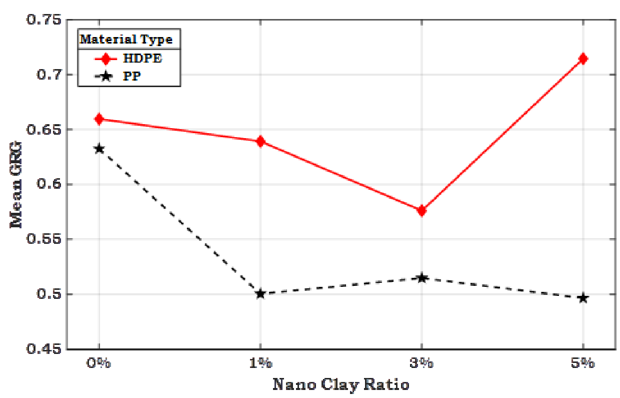

Fig.19 Grey relational grades v/s nanoclay ratio.

Moreover, the optimum parameter levels for PP nanoclay composites polymers are: Laser power is 0.5987 (Level 1), cutting speed is 0.6114 (level 3) and nanoclay ratio is 0.6324 (level 1). Subsequently the higher grey relational grade from each level of factor indicates the optimum level. It is concluded that the optimum parameter level for laser power, cutting speed and nanoclay Ratio is level 1 (72 W), level 3 (6 mm/s), and level 1 (0%) respectively.

V. CONCLUSIONS

A. *ANOVA Analysis*

For both nanoclay composites polymers the cutting speed is the most significant parameter affecting metal removal rate and the other factors have insignificant effect. .Furthermore, nanoclay ratio is the most significant parameter affecting the (HAZ) followed by laser power and cutting speed.

Fore HDPE nanoclay composites polymer the laser power is the most significant parameter affecting kerf width followed by nanoclay ratio; however, the cutting speed has insignificant effect. Moreover, for PP nanoclay composites polymer the laser power is the most significant parameter affecting kerf width followed by cutting speed; however, the nanoclay ratio has insignificant effect.

For HDPE nanoclay composites polymer nanoclay ratio is the most significant parameter affecting the dross followed by cutting speed; however, the laser power factor has insignificant effect. While, for PP nanoclay composites polymer the cutting speed is the most significant parameter affecting the dross followed by nanoclay ratio; however the laser power factor has insignificant effect.

B. *Single Objective Optimization*

For HDPE nanoclay composites polymer the maximum metal removal rate was obtained by setting the laser power at 120 W, cutting speed at 7 mm/s and additive 5% nanoclay ratio. Moreover, the minimum kerf width was obtained at laser power of 72 W, cutting speed of 6 mm/s and additive 5% nanoclay ratio. Also, the minimum heat affected zone value was obtained at laser power of 72 W, cutting speed of 7 mm/s and using the pure HDPE without any additions of the nanoclay material.

Also, the optimal combination of cutting parameters for HDPE nanoclay composites polymer to minimize the dross value are obtained by setting the laser level at 120 W followed by 84 W, cutting speed at 4 mm/s, and additive 5% nanoclay ratio. For PP nanoclay composites polymer the maximum metal removal rate is obtained by setting the power at 120 W, cutting speed at 7 mm/s and using the pure PP without any additions of nanoclay material. While, the minimum kerf width was obtained at laser power 72 W, cutting speed at 6 mm/s and additive 5% nanoclay ratio. Moreover, the minimum heat affected zone value is obtained at laser power of 102 W, cutting speed of 6 mm/s and using the pure PP without any additions of nanoclay material.

Finally the optimal combination of cutting parameters for PP nanoclay composites polymer to minimize the dross value are obtained by setting the power level at 84 W, cutting speed at 6 mm/s, and using the pure PP without any additions of nanoclay material.

C. *Grey Analysis*

For HDPE nanoclay composites polymer the all cut qualities are optimized at high cutting speed of 7 mm/s, low laser power 72 W and additive 5% nanoclay ratio. Moreover, for PP nanoclay composites polymer the all cut qualities are optimized at cutting speed of 6 mm/s, low laser power 72 W and pure PP without any additions of the nanoclay material.

Finally these results could become a reference for laser cut manufacturers especially when cutting HDPE and PP nanoclay composites polymers. It would be possible to manufacture parts with certain accuracy requirements using the results instead of trial and error. Therefore, the producing time and manufacturing costs will be decreased

TABLE 7
GREY RELATIONAL GRADES AT EQUAL WEIGHTING FACTOR.

	Factors			HDPE		PP	
Exp.	Laser Power (W)	Cutting Speed (mm/s)	Nano ratio (%)	γ_j	order	γ_j	order
1	72	2	0	0.5094	14	0.5167	9
2	72	4	1	0.6872	7	0.6245	5
3	72	6	3	0.6815	9	0.6271	3
4	72	7	5	0.9022	1	0.6263	4
5	84	2	1	0.5125	13	0.3812	15
6	84	4	0	0.6928	5	0.5384	8
7	84	6	5	0.7366	4	0.5692	6
8	84	7	3	0.7419	3	0.4764	12
9	102	2	3	0.4394	16	0.4155	14
10	102	4	5	0.6476	11	0.4202	13
11	102	6	0	0.6817	8	0.7691	1
12	102	7	1	0.6690	10	0.5157	10
13	120	2	5	0.5708	12	0.3705	16
14	120	4	3	0.4411	15	0.5398	7
15	120	6	1	0.6876	6	0.4803	11
16	120	7	0	0.7538	2	0.7053	2

TABLE 8
MEAN GREY RELATIONAL GRADE FOR EACH FACTOR LEVELS

	Level 1		Level 2		Level 3		Level 4	
Factors	HDPE	PP	HDPE	PP	HDPE	PP	HDPE	PP
P (W)	0.6951	0.5987	0.6709	0.4913	0.6094	0.5301	0.6133	0.5240
S (mm/sec)	0.5080	0.4210	0.6172	0.5307	0.6968	0.6114	0.7667	0.5809
N (wt %)	0.6594	0.6324	0.6391	0.5004	0.5760	0.5147	0.7143	0.4966

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