International Journal of Engineering &Technology, *7 (3.12) (2018) 885 -893*

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Optimization on Cryogenic Co_2 Machining Parameters of AISI D2 Steel using Taguchi Based Grey Relational Approach and TOPSIS

V.Balaji[1], S. Ravi[2], P.Naveen Chandran[3]

[1]Research scholar, Department of Mechanical Engineering ,
Bharath Institute of Higher Education And Research (BIHER) , Chennai, India.
[2]Professor, Department of Mechanical Engineering, Sriram College of Engineering, Chennai, India.
[3]Professor, Department of Automobile Engineering,
Bharath Institute of Higher Education and Research (BIHER), Chennai, India.
**Corresponding Author Email: [1]vbalaji_b1980@yahoo.co.in, [2]vpsravi@gmail.com, [3]asiriyan@gmail.com*

Abstract

The Machinability, and the process parameter optimization of Cryogenic CO_2 machining operation for AISI D2 steel have been investigated based on the Taguchi based grey approach and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS).In this examination work, the measure of the work materials utilized was AISI D2 Steel of size is 150mm × 50 mm × 50m with SANDWIK influence CVD To TiN coated carbide cutting insert tool device embed was utilized. The time taken for machining is 5 min and profundity of cut were kept up steady with various lower cutting velocities, and diverse encourage rate. An L27 orthogonal array was selected for planning the experiment. Cutting speed, depth of cut and feed rate were considered as input process parameters. Cutting force (Fz) and surface roughness (Ra) were considered as the performance measures. These performance measures were optimized for the improvement of machinability, quality of product. A comparison is made between the multi-criteria decision making tools. Grey Relational Analysis (GRA) and TOPSIS are used to confirm and prove the similarity. To determine the influence of process parameters, Analysis of Variance (ANOVA) is employed. The end results of experimental investigation proved that the machining performance can be enhanced effectively with the assistance of the proposed approaches.

Keywords: *Cryogenic machining CO_2, Design of experiments, Grey Relational Analysis, TOPSIS.ANOVA.*

1. Introduction

The customary machining assumes a critical part in the little scale enterprises, yet little scale businesses confronting the issues in machining are High cutting temperature influences instrument wear, dimensional exactness, the surface unpleasantness of the item, extreme device wear cause cutting apparatuses disappointment. What's more, poor chip development in this manner the cooling applications in machining activities assume an imperative part and numerous tasks cannot be completed proficiently without cooling. So it is vital to apply the slicing liquids to lessen the contact, and evacuate the warmth as ahead of schedule as could be expected under the circumstances. **Yakup yildz et al. (2008), and Paul et.al, (2001)** recommended that Conventional coolants cause distinctive chemicals that may cause water contamination, soil tainting and medical issues if arranged without required medications. Another method for diminishing the slicing temperature is to utilize a cryogenic coolant,[1, 2]

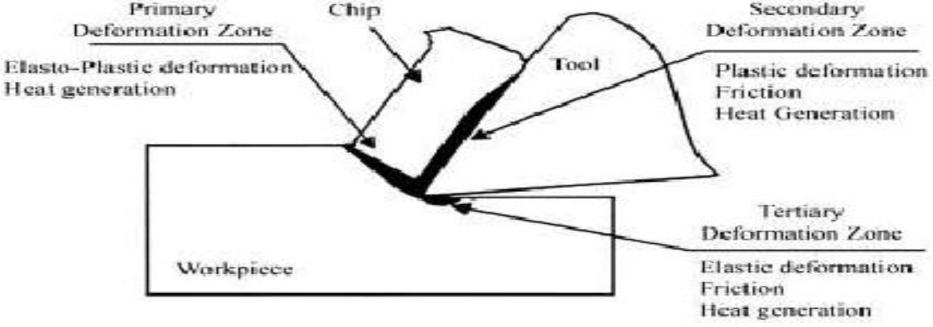

Fig. 1: chip formation and heat generation in metal cutting

Cryogenic machining is a term alluded to machining task directed at low temperature at lower than 120° K. In cryogenic medium is the super frosty medium condensed gases is coordinated into the cutting zone and it assimilates the warmth on the cutting zone at long last it vanishes into the climate. The majority of the creator's had utilized cryogenic process and have described that better instrument life, lessened cutting temperature, better surface completely and decreased cutting forces were picked up **(De Chiffre et.al 2007**) The exploration paper, recommend that cryogenic coolants give a few advantages in machining when contrasted with other cooling process in machining. In the machining procedure both nitrogen and carbon dioxide are utilized as cryogenic coolant, on the grounds that these coolant is natural well disposed clean innovation for accomplishing attractive control cutting temperature and improvement of hardware life. [3]

2. Literature Review

The processing procedure contrast with other machining process is moderate and having a low creation rate and subsequently different research, researcher and specialists are endeavoring to overcome with impacts of hardware choice and attempt to control high cutting temperature utilizing as an alternate coolant. The principle elements of cryogenic cooling in the metal slicing Process is to expel the warmth successfully from the cutting zone, bringing down the cutting power and adjusting the frictional attributes at the chip-apparatus interfaces lastly this cryogens dissipate into the air

Sandeep Kumar et al. (2016) Compared to dry and wet machining, in LN2 machining, by and large the apparatus wear is diminished 0.75 times. The surface harshness change is 17.84%. F_x drive records a decline of 0.25 times and furthermore, he demonstrated that the utilization of cryogenic coolant general builds the machining execution when contrasted with dry machining [4]

Bolewar A.B et al (2016) watched that cryogenic machining is an elective strategy to decrease the cutting temperature emerges amid the machining procedure. Decrease of cutting temperature in the scope of 9-19% was seen at rapid (145 m/min) contrasted with wet machining. [5]

Munish Gupta et.al (2015) completed the Experimental Investigation of Machining AISI 1040 Medium Carbon Steel Under Cryogenic Machining and Compared with Dry Machining reasoned that in general the apparatus wear were decreased to 55.45 and 65.53 %, surface unpleasantness was lessened to 125.90 % and powers were diminished to 61.94 and 96.60 %.therefore The test comes about demonstrated that the use of cryogenic coolant general expands the machining execution when contrasted with dry machining [6]

Akshaya T Poojary et.al(2014) "Examination on machinability of AISI 1040 steel" watched that the cutting powers were less at rapid in cryogenic machining, and furthermore infers that an amazing surface complete can be acquired receiving cryogenic cooling (plunge technique). [7]

Sunil Magadum et al (2014) "Cryogenic Machining of SS304 Steel" Coated carbide CNMG 120404 Insert was utilized as a cutting device. Apparatus wear, device life and cutting powers were estimated. The outcomes have uncovered that cryogenic machining has yielded better device life when contrasted with traditional surge machining.[8]

Ampara Aramcharoen et each of the (2014) "An Experimental Investigation on cryogenic processing of Inchonal 718 and its supportability evaluation" reasoned that outcomes exhibited that the cryogenic cooling is promising for machinability and maintainability a contrasted with the oil based coolant and dry cutting in term of hardware sport decrease, less erosion at the optional twisting zone, bring down vitality utilization and defilement free on machined part. [9]

B.Dilip Jerold and M.Pradeep Kumar et al.(2011) Investigated the execution of cryogenic coolant, for example, CO2 and LN2 in turning of AISI 1045 steel answered to cryogenic CO2 diminishes the slicing powers to around 2-12% and enhanced the surface unpleasantness 2-14% of the machined part. Apparatus wears additionally be less on the use of CO2 when contrasted with the wet and LN2 [10]

M. Dhananchezian, M.Preadeep Kumar, (2011) Study the Effect of Cryogenic Cooling With Modified Cutting Tool Insert in the Turning of Ti-6al-4v Alloy" demonstrated that cryogenic cooling with an adjusted cutting apparatus embed have indicated better outcomes on the cutting temperature, cutting power and surface harshness over wet machining. [11]

Trausti stefansson et at (2011) "Use of cryogenic coolants in Machining process" SANDVIK coroment,[4] revealed utilizing a cryogenic cutting liquids for machining has an extraordinary mechanical and practical potential .and it relies on work piece material ,cutting apparatus material, outline of the device and process parameter [12]

Dhananchezian et.al (2011) directed "Exploratory Investigation of Cryogenic Cooling by Liquid Nitrogen in the Orthogonal Machining Process" watched that in cryogenic cooling technique, the temperature was diminished to 19– 28% and the slicing power was expanded to a most extreme of 15% at that point dry machining of AISI 1045 steel. In machining of Aluminum 6061-T6 combination, the temperature was diminished to 27– 39% and the slicing power was expanded to a greatest of 10%.[13]

The demand for using special type of AIS D2 steel is increasing in many of the engineering applications. AISI D2 steel is extensively used Blanking and punching bites to withstand high pressure and superb holding properties.Machining can be done on AISI D2 Steel at any obtainable condition due to its ductile property. Compared with the other alloy steels, and it provides dimensional stability and scraped area protection.

Paulo Davim et al.(2008) Reported the importance of predicting surface integrity of 15-5 PH stainless steel which makes more attention in nuclear and aerospace applications.[14]. **Kumar et al.**(2013) concluded that 15-5 PH is more predominant than 17-4 PH stainless steel. In the solution treated condition this material can be machined at the rate similar to SS 304. [15]

Aldo Braghini Junior et al. (2009) Explained that during machining 15-5 PH stainless steel, lubricating and cooling condition, mostly affect the mechanism of tool wear and the life of the tool. It was concluded that the importance should be given to tool lubrication than tool cooling to overcoming tool damage due to temperature variations and the selection of cutting fluid has also influenced on tool damage.[16]

Fnides et al.(2016) observed that cutting forces are the salient parameter to evaluate the essential power required for machining and are also considered while dimensioning and designing the machine components. Cutting forces have significant influences on deformation, dimensional accuracy, machining system and chip formation of machined workpiece. [17]

Noordin et al.(2007) observed that longer tool life and better surface finish were achieved at higher nose radius, low depth of cut and low feed rate while turning hardened stainless steel.[18].

Axinte et al.(2002)Explained that the most significant factor which affects the quality of machined part is surface roughest. The poor surface quality during machining of difficult to machine material is due to variation in cutting temperature produced, higher cutting speed and higher feed rate. The higher temperature produced during machining is the main cause for dimensional deviation and cutting tool failure. [19]

Prasanna et al.(2014) evaluated the process performance of hole drilling through overcut, thrust force, taper and circularity. Mathematical modelling and multi-performance characteristics optimization of machining parameters were done using GRA.

The results revealed that thrust force is controlled by cutting velocity and feed. The most significant parameters that affect dimensional accuracy of the hole are cutting speed and pressure of air.[20]

E.Kuram and B. Ozcelik.(2013) Experimental work using ball nose in an end mill cutter in micro-milling of aluminium was carried out with four different stages such as modelling, experimental work, single and multi-objective optimization. The process parameters and their effects onthe responses were optimized by GRA and ANOVA [21].

Tzeng et al. (2009) developed grey relational approach technique to find the optimal machining parameters in CNC turning and identified that the most influencing parameter that affects roughness average is the depth of cut. The roughness and roundness are mostly influenced by cutting velocity. The most significant factor was calculated using ANOVA and found that the depth of cut influences more than other parameters.[22]

C. Camposeco-Negrete.(2013) conductedTurning experiments on AISI 6061 T6 were performed in rough condition to optimize the machining process parameters. It was concluded that machining at higher feed rates reduced the energy consumption, but increased the surface roughness [23].

Y. Tansel İç(2012) conducted Design of Experiment (DOE) and TOPSIS method for identifying the critical selection and interaction of attributes using multiple linear regression analysis by fitting appropriate polynomial in the experimental data. [24]

Gadakh(2012) developed TOPSIS method to solve multiple criteria optimization problem and stated that it is an effective tool for complicated decision making.[25] **Y. Tansel İç (2014)** used both Design of Experiment and TOPSIS methods together to rank the companies and with the help of developmental model, satisfactory results were obtained in the real-time financial environment. [26]

Vinodh et al.(2014) made an assessment model, based on Analytic Hierarchy Process (AHP) and TOPSIS, in a fuzzy environment to carry out performance evaluation to identify the best method for recycling plastics among the various plastic recycling processes. This present study investigates the impact of different process parameters, particularly on cutting force (F_z) and surface roughness (Ra) in CNC turning of 15-5 PH steel in the as received condition. Experiments are planned based on Taguchi design method. The outcomes are investigated to attain optimal cutting force (F_z) and surface roughness (Ra). A comparison is made between the multi criteria decision making tools of Grey Relational Analysis (GRA) and TOPSIS to ensure the similarity between them. The most influencing parameters which affect the outputs were investigated by performing ANOVA using statistical software Minitab 17.[27]

3. Materials and Experimental Details

3.1 Work Piece Material

Harry Chandler et al(1995) Tool and bite the dust steels are high-carbon, high-chromium steel and is having high hardness quality and wear safe. AISI D2 steel is the most alloyed icy work instrument steel. The steel is high in both carbon and chromium to form extensive volumes of auxiliary chromium carbides because of the precipitation of the carbides amid the hardening methodology. This offered ascend to a high wear protection steel. The work piece made for the work materials is Blanking and punching bites the dust with superb holding properties, scraped area protection and dimensional strength. In this examination work, the extent of the work materials utilized was 150mm × 50 mm × 50mm. Mechanical properties and concoction creation of AISI D2 Steel are given roar in the table 1 and 2 [28]

Table 1: Chemical Composition of AISI D2 Steel

Element	Amount (%)
Carbon	1.50-1.70
Silicon	0.10-0.35
Manganese	0.25-0.50
Chromium	11.00-13.00
Molybdenum	0.80 max
Vanadium	0.80 max
Iron	Balance

Table 2: Mechanical properties of AISI D2 Steel

Mechanical Property	Metric Value
Hardness Rockwell C	62
Density	7.7 x 1000 kg/m^3
Poisson ratio	0.27-0.30
Elastic modulus	190-210GPa
Thermal conductivity	20(W/mK)

3.2 Cutting Tools

Processing tests were utilizing file capable cutting apparatus inserts. In this test embeds have been utilized as a part of the examination work are SANDWIK influence CVD To TiN covered carbide cutting instrument embed of R390-11 T3 08M-PM-1025. The Figure demonstrates the cutting instrument embeds are utilized as a part of this investigation

Fig. 2: Photographic view-cutting tool insert

3.3 Tool Holder

A typical apparatus holder was utilized for machining all the three work pieces, in all the cutting conditions. The entire determinations of the device holder are given beneath and Figure demonstrates the photographic perspective of the device holder

Tool Holder Specification

Shank diameter	: 16 mm
Overall length	: 50 mm
Header length	: 27 mm
Number of inserts	: 2

Fig. 3: Tool holder Insert

3.4 Experimental Condition

The experimental conditions for cryogenic machining is given below in the table 3.

Table 3: Experimental Condition

Work piece material & size	AISI D2 steel 50x50x150mm
Cutting tool insert	SANDVIK R390-11-T308-MPM 1030
Cutting velocity (m/min)	17.84m/min, 45.24m/min, 70.37m/min
Feed rate (mm/rev)	0.034mm/rev,0.074mm/rev,0.150mm/rev
Depth of cut (mm)	0.2,0.4,0.6mm
Machining Time	5 min

3.5 Cryogenic Milling CO$_2$

The test setup for cryogenic processing CO2 for the estimation of cutting power and temperature amid the cryogenic processing. For estimating, cutting powers processing instrument dynomometer and apparatus chip interface temperature was evaluated by 6 channel K-type thermocouple are utilized and Carbon dioxide chamber associated with the adornments is as appeared in roar fig 5. (Photographic view)

Fig. 5: Cryogenic CO_2 Setup

In this technique CO2 Cylinder is appended with weight controller the controller utilized for this reason comprises of two dial pointers, one showing the barrel weight and the other demonstrating the supply weight by the controller. The Carbon dioxide stream meter is joined to gauge the measure of stream of the carbon dioxide coolant. One end of an elastic hose is associated with the outlet of the stream meter, and the opposite end to the valve for to stop the stream, from the valve spout is associated with the point towards the slicing zone to supply the Cryogenic CO2 while the machining activity is done.

3.6 Design of Experiments

Taguchi method is one of the powerful tools for improving the productivity at low cost. To study the whole parameter space with a small number of experiments, Taguchi method uses a special design of orthogonal arrays [23– 25]. The methodology of Taguchi for 3×3 levels, an L27 orthogonal array was used to outline the trail conditions in the implementation of the plan of experiments. Table 4 shows the cryogenic machining process parameters and their levels.

Table 4: Machining process parameters and their levels

Parameter	Unit	Level I	Level II	Level III
Cutting speed (Vc)	m/min	17.84	45.24	70.37
Feed rate (f)	mm/rev	0.034	0.074	0.150
Depth of cut (ap)	mm	0.2	0.4	0.6

Each experiment of the L27 trials was repeated twice and the average values of response were tabulated for the analysis. Table 5 shows the experimental plan and average test results for the cryogenic machined experiments. From the literature survey, it has been observed that to analyse and find the best parameter of single performance characteristics Taguchi method can be applied. Whereas, in analysing test results of multi-performance characteristics, Grey Relational Analysis (GRA) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) can be used effectively.

Table 5: Experimental layout and corresponding results of cryogenic machined cutting force and surface roughness using L27 orthogonal array

Exp. No	Cutting speed (Vc)	Feed rate (f)	Doc (ap)	Cutting force (F_R) N	Surface roughness (Ra) µm
1	17.84	0.034	0.2	83.25	0.54
2	17.84	0.034	0.4	222.64	0.65
3	17.84	0.034	0.6	302.12	0.51
4	17.84	0.074	0.2	130.24	1.13
5	17.84	0.074	0.4	251.24	1.19
6	17.84	0.074	0.6	390.75	1.22
7	17.84	0.150	0.2	196.50	1.66
8	17.84	0.150	0.4	315.50	1.88
9	17.84	0.150	0.6	468.22	1.99
10	45.24	0.034	0.2	104.13	0.53
11	45.24	0.034	0.4	183.47	0.65
12	45.24	0.034	0.6	279.38	0.87
13	45.24	0.074	0.2	127.02	1.13
14	45.24	0.074	0.4	236.97	1.08
15	45.24	0.074	0.6	382.82	1.21
16	45.24	0.150	0.2	180.76	1.58
17	45.24	0.150	0.4	251.84	1.64
18	45.24	0.150	0.6	431.36	1.87
19	70.37	0.034	0.2	95.37	0.30
20	70.37	0.034	0.4	160.00	0.59
21	70.37	0.034	0.6	260.09	0.51
22	70.37	0.074	0.2	105.12	0.73
23	70.37	0.074	0.4	207.13	0.74
24	70.37	0.074	0.6	351.11	0.88
25	70.37	0.150	0.2	172.73	1.33
26	70.37	0.150	0.4	263.68	1.41
27	70.37	0.150	0.6	405.62	1.63

4. Optimization

4.1 Grey Relational Analysis

Experimental results are integrated with a Grey Relational Approach to investigate the three machining parameters (cutting speed, feed rate and depth of cut) at three levels with respect to surface roughness and cutting force.
The steps involved in GRA are as follows
Step 1: According to the experimental plan all the experimental results are obtained and tabulated.
Step 2: Usually data normalization is of three types, namely Nominal the Best (NB), Higher the Better (HB) and Lower the Better (LB) [24, 25]. In this experimental study, lower the better criteria have been chosen for cutting force and surface roughness. Hence equation (1) is used for normalization of the original sequence of this response.

$$y_i^*(k) = \frac{\max y_i(k) - y_i(k)}{\max y_i(k) - \min y_i(k)} \quad \ldots \qquad (1)$$

Where Y_i^* (k) is the normalized data, i.e. after grey relational generation, max $y_i(k)$ is the highest value and min $y_i(k)$ is the lowest value of $y_i(k)$ for the kth response and $y_i(k)$ is the kth response of the ith experiment.
Step 3: Grey Relational Coefficient (GRC) is calculated using the following equation.

$$\varepsilon_i(k) = \frac{\Delta \min + \omega \Delta \max}{\Delta_{oi}(k) + \omega \Delta \max} \quad \ldots \qquad (2)$$

where $\varepsilon_i(k)$ is the Grey Relation Coefficient (GRC), Δ max is the highest value of $\Delta_{oi}(k)$,Δ min is the lowest value of $\Delta_{oi}(k)$, $\Delta_{oi}(k)$ = !!$y_{o*}(k)$ – $y_i*(k)$!!i.e., absolute of the difference between y_o^* (k) and $y_i*(k)$. y_o* (k) is the ideal or reference sequence.
Step 4: The grey relational grade (Γi) is found using the following relation

$$\Gamma_i = \frac{1}{n} \sum_{i=1}^{Q} \varepsilon_i(k) \quad \ldots \qquad (3)$$

Where Q is the total number of responses and n is the number of output responses. The parameter which has the highest value of the grey relational grade is the optimal machining condition of the selected set of experiments.

4.2 TOPSIS

TOPSIS method is used for the selection of the best alternative from the available alternatives and the steps involved are as follows.

Step 1: The twenty seven alternatives are evaluated. In this specific problem, the attributes are cutting force and surface roughness which are considered as non-beneficial (lower values).
Step 2: All the information available is presented in the form of a decision matrix. Table 5 shows the D 27×3 matrix.
Step 3: Equation (4) is used to normalize the output values of the machining process, Table 9 shows the normalized matrix of R 27×3.

$$R_{ij} = x_{ij} \Big/ \sqrt{\sum x_{ij}^2} \quad \text{for} \quad i = 1, \ldots, m, \;\; j = 1, \ldots, n. \qquad (4)$$

Step 4: According to the relative importance of attributes, weights are considered. All attributes are considered as equal, the associated weights are F_R = 0.5; Ra = 0.5 and the sum of weight is one. Using equation (5) weighted, normalized decision matrix is constructed.

$$V_{ij} = w_j R_{ij} \quad \ldots \qquad (5)$$

Where: j = 1, 2 . . . n, i = 1, 2 . . . m; here wj is the weight of the jth attribute. Step 5: Equations (6) and (7) are used to determine the positive ideal solution (PIS) A∗ and negative ideal solution (NIS) A' .

$$A^* = \{V_1^*, \ldots, V_n^*\}, \quad \text{where } V_j^* = \{\max(V_{ij}) \text{ if } j \in J;\ \min(V_{ij}) \text{ if } j \in J'\}, \qquad (6)$$

$$A' = \{V_1', \ldots, V_n'\}, \quad \text{where } V_j' = \{\min(V_{ij}) \text{ if } j \in J;\ \max(V_{ij}) \text{ if } j \in J'\}, \qquad (7)$$

Where J' is a set of cost attributes and J is a set of beneficial attributes.
Step 6: Equations (8) and (9) are used to find the separation measures, from the positive ideal and negative ideal solution.

$$S_i^* = \left[\sum (V_j^* - V_{ij})^2\right]^{1/2} \quad i = 1, \ldots, m \qquad (8)$$

$$S_i' = \left[\sum (V_j' - V_{ij})^2\right]^{1/2} \quad i = 1, \ldots, m. \qquad (9)$$

Step 7: Equation (10) is used to calculate relative closeness to the ideal solution.

$$C_i^* = S_i' / (S_i^* + S_i') \quad 0 \leqslant C_i^* \leqslant 1. \qquad (10)$$

Step 8: The alternatives are ranked based on the closeness index in descending order. The alternative having greater C ∗ i value shows the improved performance.

4.3 Analysis of Variance

Statistical method ANOVA is used to find the effect and impact of every individual parameter on results. The effect of individual parameters cannot be assessed using Taguchi method, while ANOVA well determines the percentage contribution of individual parameters. Statistical software Minitab17 was used to model and investigate the effect of machining parameters (cutting speed, feed rate and depth of cut) on individual responses and multiple responses.

5. Results and Discussion

5.1 Cryogenic CO_2Effect of Process Parameters on Cutting Force

The influence of Cryogenic CO_2 process parameters on cutting force is shown in Fig. 6. The cutting force declines with increasing cutting speed.

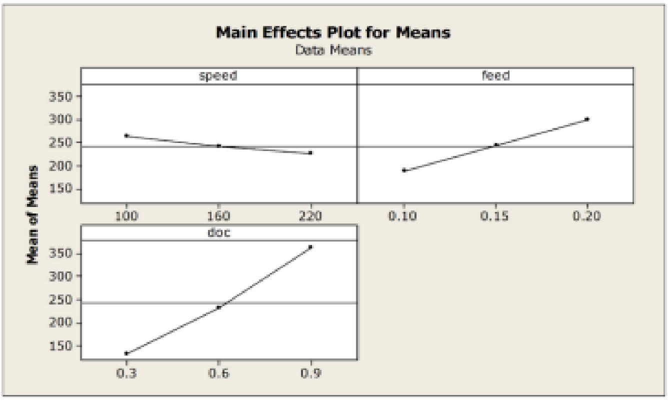

Fig. 6: Cryogenic CO_2 Effects plots for Cutting force

Whereas at lower cutting speed, the cutting force required is higher due to the effect of the coefficient of friction between the tool and workpiece. While machining at higher speed, the temperature generated is greater at the cutting zone or the tool-work interface which makes the workpiece softer and hence the material removal is possible at lower cutting force. Whilst the increase in feed rate, the cutting force increases due to the more contact length of tool insert and work material at all speeds. Similarly, an increase in depth of cut increases the cutting force. Moreover, the material removal rate is high at deeper cuts which require higher cutting force. Table 6 shows the response for means of cutting force and it is found that the major factor affecting the cutting force is the depth of cut followed by the feed rate and the cutting speed.

Table 6: Response table for means of Cryogenic CO_2ofCutting force

Level	Cutting speed (Vc)	Feed (f)	Doc (ap)
1	262.3	187.8	132.8
2	242	242.5	232.5
3	224.5	298.5	363.5
Delta	37.7	110.6	230.7
Rank	**3**	**2**	**1**

Table 7 illustrates the results of ANOVA for Cryogenic CO_2 cutting force. It shows that the depth of cut is the most influencing parameter that affects the cutting force and the percentage of contribution is about (77.34%) and it is trailed by feed rate (17.68%) and the cutting speed (2.06%) respectively.

Table 7: ANOVA for Cryogenic $CO_2$of Cutting force

Source	DF	Seq SS	Adj SS	Adj MS	F	% C
Speed	2	6420	6420	3210	32.61	2.06
Feed	2	55088	55088	27544	279.86	17.68
DOC	2	240982	240982	120491	1224.23	77.34
speed·feed	4	853	853	213	2.17	
feed·doc	4	5568	5568	1392	14.14	
speed·doc	4	1879	1879	470	4.79	
Error	8	787	787	98		
Total	26	311578				

5.2 Cryogenic CO_2 Effect of process parameters on surface roughness

Fig. 7 illustrates the Cryogenic CO_2effect of process parameters on surface roughness. When the level of cutting speed increases from 17.84 to 70.37 m/min, the value of surface roughness reduces due to thermal softening of workpiece. The increase in feed and depth of cut causes friction due to increase in contact length between work material and tool edge interface. Hence, the value of surface roughness increases. The response for means of surface roughness is shown in Table 9 and it is found that, for the selected set of parameters, the major factor which affect the surface roughness is in the order of feed rate followed by cutting speed and depth of cut. Table 10 shows the results of ANOVA for surface roughness. It implies that the most significant parameter affecting the surface roughness is the feed rate (86.07%) and it is followed by cutting speed (7.62 %) and the depth of cut (2.72%) respectively

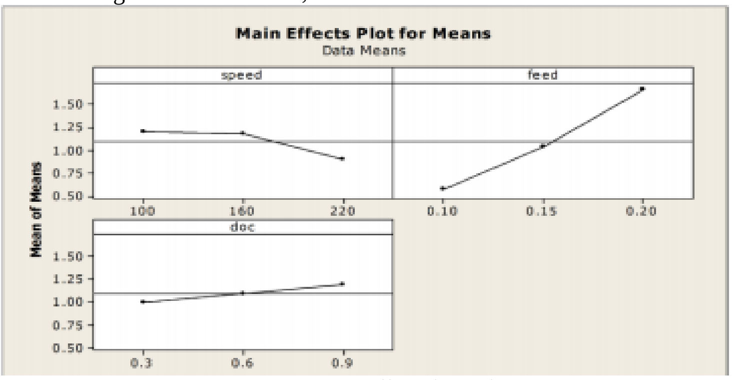

Fig. 7: Cryogenic CO_2 Main Effects for surface roughness

Table 9: Response table for means of Cryogenic CO$_2$of surface roughness

Level	Cutting speed (Vc)	Feed (f)	Doc (ap)
1	1.1955	0.5716	0.9921
2	1.1737	1.0344	1.0918
3	0.9021	1.6654	1.1875
Delta	0.2934	1.0938	0.1954
Rank	2	1	3

Table 10: ANOVA for Cryogenic CO$_2$ of Surface roughness

Source	DF	Seq SS	Adj SS	Adj MS	F	% C
Speed	2	0.48103	0.48103	0.2405	48.43	7.62
Feed	2	5.42629	5.42629	2.7131	546.34	86.07
DOC	2	0.17192	0.17192	0.0859	17.31	2.72
speed·feed	4	0.10307	0.10307	0.0257	5.19	
feed·doc	4	0.05266	0.05266	0.0131	2.65	
speed·doc	4	0.03	0.03	0.0075	1.51	
Error	8	0.03973	0.03973	0.0049		
Total	26	6.3047				

5.3 Evaluation of Cryogenic CO$_2$ by Multiple objective optimization method using GRA and TOPSIS

Table 11shows the Evaluation of Cryogenic CO$_2$responses table for both cutting force and surface roughness .It is found that the optimal process parameter set is the 19th experiment having levels of Vc*3 f1* ap*1* which means the cutting speed is 70.37 m/min, feed rate is 0.034 mm/rev and depth of cut is 0.2 mm. A similarity with Taguchi method is found from the response table of the grey relation grade which shows the feed rate is the most influencing factor, followed by the depth of cut and speed. Table 12illustrates the Cryogenic CO$_2$grey relational grade for all trials using L27 orthogonal array. If the grey relational grade is higher, the product quality will be better. Consequently, on the basis of grey relational grade, the effect of individual factor can be assessed and also the best level for each controllable factor can be identified..

Fig. 8shows the Cryogenic CO2 of Main effects plots for grey relational grade graph for the levels of the processing parameters and it is found that the speed (70.37 m/min) at third level, feed (0.034 mm/rev) at first level and depth of cut (0.2 mm) at first level are the optimum parameters of multi performance characteristics

Table 11: Cryogenic CO$_2$Response table for grey relational grader (GRA)

Level	Cutting speed (Vc)	Feed (f)	Doc (a_p)
1	0.5561	0.7333	0.7111
2	0.5609	0.5720	0.5635
3	0.6334	0.4451	0.4758
Delta	0.0773	0.2882	0.2353
Rank	3	1	2

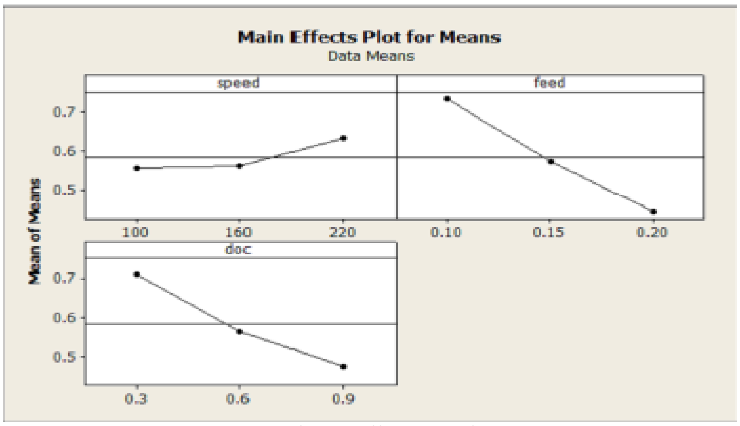

Fig. 8: Cryogenic CO2 of Main effects plots for grey relation grade

Table 12shows the evaluated relative closeness (Ci) and Rank of TOPSIS for Cryogenic CO$_2$ Machining. The best combination of machining parameters in machining can be arranged as 19-1-10-22-20-11-2-23-21-3-13-4-25-12-14-5-16-24-7-26-17-15-6-8-27-18-9 through TOPSIS.

Table 12: Evaluated Relative Closeness (Ci) and grade values for Cryogenic CO$_2$ Machining

Exp. No	Normalised Value		Grey Relational Co-efficient after Weighted		Grey relation grade	Rank
	Cutting force (F_R)	Surface roughness	Cutting force (F_R)	Surface roughness		
1	1	0.8573	1	0.7779	0.8889	2
2	0.6379	0.7940	0.5799	0.7082	0.6441	10
3	0.4314	0.8764	0.4679	0.8018	0.6348	11
4	0.8779	0.5084	0.8037	0.5042	0.6540	9
5	0.5636	0.4730	0.5339	0.4868	0.5104	17
6	0.2012	0.4552	0.3849	0.4785	0.4317	23
7	0.7058	0.1974	0.6295	0.3838	0.5067	18

8	0.3967	0.0656	0.4531	0.3485	0.4008	24
9	0	0	0.3333	0.3333	0.3333	27
10	0.9457	0.8628	0.9021	0.7847	0.8434	3
11	0.7396	0.7922	0.6576	0.7064	0.6820	6
12	0.4905	0.6621	0.4953	0.5968	0.5460	14
13	0.8863	0.5084	0.8147	0.5042	0.6595	8
14	0.6006	0.5380	0.5559	0.5197	0.5378	15
15	0.2218	0.4611	0.3911	0.4813	0.4362	22
16	0.7467	0.2406	0.6637	0.3970	0.5303	16
17	0.5620	0.2069	0.5330	0.3866	0.4598	21
18	0.0957	0.070	0.3560	0.3498	0.3529	26
19	0.9685	1	0.9407	1	0.9703	1
20	0.8006	0.8277	0.7149	0.7437	0.7293	5
21	0.5406	0.8750	0.5211	0.8000	0.6606	7
22	0.9431	0.7449	0.8979	0.6622	0.7801	4
23	0.6782	0.7390	0.6084	0.6570	0.6327	12
24	0.3042	0.6562	0.4181	0.5926	0.5053	19
25	0.7675	0.3900	0.6826	0.4504	0.5665	13
26	0.5313	0.3429	0.5161	0.4321	0.4741	20
27	0.1626	0.2128	0.3738	0.3884	0.3811	25

Table 13: Evaluated Relative Closeness (Ci) and Rank of TOPSIS for Cryogenic CO_2 Machining

Exp. No	Cutting force	Surface roughness	Normalised decision matrix (Ri j)		Weighted normalised value (Vi j)		Separation measures		Relative closeness	Rank
	(F_R)	(Ra)	(F_R)	(Ra)	(F_R)	(Ra)	S_i^*	$S_i^'$	C_i^*	
1	83.25	0.54	0.0603	0.0871	0.030	0.0435	0.0194	0.1820	0.9033	2
2	222.64	0.65	0.1613	0.1043	0.080	0.0521	0.0577	0.1401	0.7081	7
3	302.12	0.51	0.2188	0.0819	0.109	0.0409	0.0810	0.1338	0.6228	10
4	130.24	1.13	0.0943	0.1823	0.047	0.0911	0.0691	0.1407	0.6703	12
5	251.24	1.19	0.1820	0.1920	0.091	0.0960	0.0942	0.1017	0.5191	16
6	390.75	1.22	0.2831	0.1968	0.141	0.0984	0.1339	0.0681	0.3373	23
7	196.50	1.66	0.1423	0.267	0.071	0.1336	0.1169	0.1020	0.4660	19
8	315.50	1.88	0.2285	0.3031	0.114	0.1515	0.1527	0.0560	0.2684	24
9	468.22	1.99	0.3392	0.3210	0.169	0.1605	0.1951	0	0	27
10	104.13	0.53	0.0754	0.0856	0.037	0.0428	0.0201	0.1768	0.8975	3
11	183.47	0.65	0.1329	0.1048	0.066	0.0524	0.0460	0.1494	0.7643	6
12	279.38	0.87	0.2024	0.1403	0.101	0.0701	0.0846	0.1133	0.5723	14
13	127.02	1.13	0.0920	0.1823	0.046	0.0911	0.0689	0.1417	0.6728	11
14	236.97	1.08	0.1716	0.1742	0.085	0.0871	0.0841	0.1113	0.5697	15
15	382.82	1.21	0.2773	0.1952	0.138	0.0976	0.1310	0.0701	0.3485	22
16	180.76	1.58	0.1309	0.2554	0.065	0.1277	0.1094	0.1091	0.4993	17
17	251.84	1.64	0.1824	0.2646	0.091	0.1323	0.1242	0.0833	0.4013	21
18	431.36	1.87	0.3125	0.3017	0.156	0.1508	0.1788	0.0164	0.0844	26
19	95.37	0.30	0.0690	0.0481	0.034	0.0240	0.0043	0.1919	0.9776	1
20	160.00	0.59	0.1159	0.0951	0.058	0.0475	0.0364	0.1588	0.8135	5
21	260.09	0.51	0.1884	0.0822	0.094	0.0411	0.0662	0.1412	0.6805	9
22	105.12	0.73	0.0761	0.1177	0.038	0.0588	0.0356	0.1662	0.8232	4
23	207.13	0.74	0.1500	0.1194	0.075	0.0597	0.0572	0.1382	0.7070	8
24	351.11	0.88	0.2543	0.1419	0.127	0.0709	0.1077	0.0990	0.4790	18
25	172.73	1.33	0.1251	0.2146	0.062	0.1073	0.0893	0.1195	0.5723	13
26	263.68	1.41	0.1910	0.2275	0.095	0.1137	0.1109	0.0876	0.4412	20
27	405.62	1.63	0.2938	0.2630	0.1469	0.1315	0.1586	0.0368	0.1884	25

Table 14: ANOVA for Cryogenic CO_2 of Grey Relation Grade

Source	DF	Seq SS	Adj SS	Adj MS	F	% C
Speed	2	0.0337	0.0337	0.0168	64.05	4.87
Feed	2	0.3755	0.3755	0.1877	713.32	54.3
DOC	2	0.2545	0.2545	0.1272	483.45	36.8
speed·feed	4	0.0068	0.0068	0.001	6.51	0.99
feed·doc	4	0.0145	0.0145	0.0036	13.78	2.09
speed·doc	4	0.0042	0.0042	0.001	4.04	0.6
Error	8	0.0021	0.0021	0.0002		
Total	26	0.6915				

Results of analysis of variance ANOVA for Cryogenic CO_2 of the grey relational grade are shown in Table 14which indicates that the feed rate is the most significant machining parameter (54.30%) which affects the multiple performance characteristics and it is followed by depth of cut (36.80%) and the cutting speed (4.87%).Both the results of grey relational approach and TOPSIS reveals that the 19th experiment, i.e. cutting speed 70.37 m/min, feed rate 0.034 mm/rev and depth of cut 0.2 mm is the optimal parameter for obtaining better machining performance.

6. Conclusions

Cryogenic CO_2 machining operations were conducted with SANDWIK influence CVD makesTiN coated carbide insetrs were embedded on AISI D2 steel and the process parameters were analysed in terms of surface roughness and cutting force by varying the cutting speed, feed rate and depth of cut. Using grey relational analysis and TOPSIS, the multi objective optimization was performed and its optimum machining conditions were determined. The following conclusions were made.

- From GRA, the optimum Cryogenic CO$_2$ machining parameters were identified as cutting speed 70.37m/min, feed rate 0.034 mm/rev and depth of cut 0.2 mm, i.e. 19th experiment.
- From the relative closeness values of TOPSIS, the best combination of Cryogenic machining parameters can be arranged in the order19-1-10-22-20-11-2-23-21-3-13-4-25-12-14-5-16-24-7-26-17-15-6-8-27-18-9 respectively. It is identified that the cryogenic machining parameter selected as alternative 19 is the first choice. From the experimental plan (Table 5) the corresponding process parameters related to alternative 19 are cutting speed of 70.37 m/min, feed rate of 0.0.4 mm/rev and depth of cut of 0.2 mm.
- From the statistical analysis, In Cryogenic CO$_2$ machining, it is clear that depth of cut is the most influencing parameter that affects cutting force (F$_R$) while feed is the most influencing factor which affects the surface roughness (Ra). GRA is used to reveal the influencing parameter affecting both F$_R$ and Ra and it is concluded that feed rate is the predominant parameter that affects both F$_R$ and Ra.
- A similarity is found between the results of TOPSIS and GRA.

References

[1] Yakup Y and Muammer N, A review of cryogenic cooling in machining process, International Journal of Machine Tool [8] and Manufacture, 48 (2008) 947-964.

[2] Paul S, Dhar N R and Chattopadhyay A B, Benificial effects of Cryogenic cooling over dry and wet machining on tool wear and surface finish in turning AISI 1060 Steel. Journal of Materials processing technology 116, (2001) 44-48.

[3] De Chiffre et. al., Performance testing of cryogenic CO2 as a cutting fluid in parting/grooving and threading austentic stainless steel. CIRP Annals- Manufacturing technology56(1) (2007), 101-104.

[4] Sandeep Kumar, Kulbhusahan Sharma, et.al, Experimental Investigation of Machining EN 31 Steel under Cryogenic Machining: A Comparison with Dry Machining. International Journal on Emerging Technologies 7(1) (2016) 83-88

[5] Bolewar A.B et.al "Effect of Cryogenic cooling Environment using CO$_2$ on cutting Temperature in Turning process" Novateur publications IJIERT, Volume 3 issue 6 ISSN:2394-3596 (2016) 38-44

[6] Munish Gupta et.al, Experimental Investigation of Machining AISI 1040 Medium Carbon Steel under Cryogenic Machining: A Comparison with Dry Machining. Journal of the institution of Engineers (india) series C Volume 96, Issue 4, (2015) 373–379

[7] Akshaya T Poojary, Rajesh Nayak,et.al, Investigation on Machinability of AISI 1040 Steel. Proceedings of 11th IRF International Conference, Pune, India, ISBN: 978-93-84209-27-8(2014)

[8] Sunil Magadum, Arun kumar.et.al Cryogenic Machining of SS 304 Steel,AIMTDR 356-1, 356-5(2014)

[9] Ampara Armcharoen,et.al "An Experimental Investigation on cryogenic milling of Inconel 718 and its sustainability assessment" 6th CIRP International conference on high performance cutting, HPC2014,Science direct, Procedia CIRP (2014) 529-534

[10] Jerold, B.D. and M.P. Kumar Experimental investigation of turning AISI 1045 steel using cryogenic carbon dioxide as the cutting fluid. Journal of Manufacturing Processes, 13(2) (2011) 113-119

[11] Dhananchezian M, et.al Cryogenic turning of the Ti–6Al–4V alloy with modified cutting tool inserts. Cryogenics; 51(2011) 34–40

[12] Trausti Stefansson"Application of cryogenic coolants in Machining process" SANDVIK coroment, (2014)

[13] Dhananchezian M, et.al "Experimental Investigation of Cryogenic Cooling by Liquid Nitrogen in the Orthogonal Machining Process" International Journal of Recent Trends in Engineering, Vol. 1, No. 5(2011) 55-59

[14] J.P. Davim. Machining: fundamentals and recent advances. Springer Science & Business Media, (2008).

[15] A. Kumar, Y. Balaji, N. E. Prasad, G. Gouda, and K. Tamilmani. Indigenous development and airworthiness certification of 15–5 PH precipitation hardenable stainless steel for aircraft applications. Indian Academy of Sciences. Sadhana, 38(1):3–23,(2013).

[16] Braghini Junior, A.E. Diniz, and F.T. Filho. Tool wear and tool life in end milling of 15–5 PH stainless steel under different cooling and lubrication conditions. The International Journalof Advanced Manufacturing Technology, 43(7-8):756–764,(2009).

[17] Fnides and M.A. Yallese. Cutting forces and surface roughness in hard turning of hot work steel X38CrMoV5-1 using mixed ceramic. Mechanics, 70(2):73–78, (2016).

[18] M.Y. Noordin, V.C. Venkatesh, and S. Sharif. Dry turning of tempered martensitic stainless tool steel using coated cermet and coated carbide tools. Journal of Materials Processing Technology, 185(1):83–90, (2007).

[19] D.A. Axinte and R.C. Dewes. Surface integrity of hot work tool steel after high speed milling-experimental data and empirical models. Journal of Materials Processing Technology, 127(3):325–335, (2002).

[20] J. Prasanna, L. Karunamoorthy, M. Venkat Raman, S. Prashanth, and D. Raj Chordia. Optimization of process parameters of small hole dry drilling in Ti–6Al–4V using Taguchi and grey relational analysis. Measurement, 48:346–354, (2014).

[21] E.Kuram and B. Ozcelik. Multi-objective optimization using Taguchi based grey relational analysis for micro-milling of al 7075 material with ball nose end mill. Measurement, 46(6):1849–1864, (2013).

[22] C.J. Tzeng, Y.H. Lin, Y.K. Yang, and M.C. Jeng. Optimization of turning operations with multiple performance characteristics using the Taguchi method and grey relational analysis. Journal of Materials Processing Technology, 209(6):2753–2759, (2009).

[23] Camposeco-Negrete. Optimization of cutting parameters for minimizing energy consumption in turning of AISI 6061 T6 using Taguchi methodology and ANOVA. Journal of CleanerProduction, 53:195–203,(2013).

[24] computer-integrated manufacturing technologies. Robotics and Computer-Integrated Manufacturing, 28(2):245–256, (2012).

[25] V.S. Gadakh. Parametric optimization of wire electrical discharge machining using TOPSIS method. Advances in Production Engineering & Management, 7(3):157–164, (2012).

[26] Y.Tansel Iç. A TOPSIS based design of experiment approach to assess company ranking. Applied Mathematics and Computation, 227:630–647, (2014).

[27] S. Vinodh, M. Prasanna, and N.H. Prakash. Integrated Fuzzy AHP–TOPSIS for selecting the best plastic recycling method: A case study. Applied Mathematical Modelling, 38(19):4662– 4672, (2014).

[28] Harry Chandler, "Heat Treater's Guide Practices and Procedures for Irons and Steels " ASM International (1995)560-563