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A Comparative Study of R410a Coolant and Water Soluble Cutting Oil (WSCO) Fluid on the Turning Performance of AISI 1045 Steel: Surface Roughness and Tool Wear

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Abstract

In this research, the effects of two cooling conditions: Water Soluble Cutting Oil (WSCO) fluid and R410a coolant, on the tool wear rate and surface roughness of AISI 1045 steel (CK45) in turning with a high-speed steel (HSS) tool were investigated. The selected parameters were cutting speeds of 15, 25, 40 and 55 m/min, cutting depths of 0.5, 1 and 1.5 mm and feed rates of 0.05, 0.12 and 0.2 mm/rev. The results show that cooling by R410a coolant reduces the tool wear rate due to its high cooling power and better temperature control at the cutting zone compared to WSCO fluid. Based on the minimums of tool wear and surface roughness in different conditions, using R410a coolant can increase the cutting speed by 60% from 25 to 40 m/min. Also, in the optimal condition at a cutting speed of 40 m/min, cutting depth of 1 mm and feed rate of 0.05 mm/rev., tool wear, surface roughness are reduced by up to 20 and 10 times respectively. In the optimal condition, the tool wear rate and surface roughness after 60 min. of turning are reduced to 20 and 3.1 µm respectively. The effect of each input variable on tool wear and surface roughness was calculated by statistical analysis and was validated by ANOVA.

Keywords: Tool Wear,Cryogenic Cooling,Surface Roughness,Dimensional Deviation,Turning.

1. Introduction

AISI 1045 steel is highly valued in the industry, but it’s machining can be challenging, often leading to tool damage and shortened tool life. Therefore, finding ways to extend the tool life during the machining of steel is a critical focus for improving efficiency and performance [1]. Numerous studies have been conducted to empirically and analytically optimize the parameters that affect the machining and turning of AISI 1045 steel [2-4]. Abebe et al. [5] conducted a comparative study on dry and wet machining during double tool turning of AISI 1045 steel. Stojković et al. [6] determined the optimal cutting parameters for turning AISI 1045 steel with minimal energy consumption. Qasim et al. [7] investigated energy minimization through parameter optimization using in situ measurements in the turning of AISI 1045 steel. Aleksandrovich et al. [8]examined the effect of tool construction and cutting parameters on surface roughness and vibration in turning AISI 1045 steel using the Taguchi method. Modeling and optimization techniques such as ANOVA and RSM have been utilized to optimize machining conditions for AISI 1045 steel [9-11]. Hernández González et al. [10,11] applied response surface methodology (RSM) to identify the best cutting conditions for minimizing flank wear in high-speed dry turning of AISI 1045 steel. Hwang et al. [12] investigated MQL and wet turning processes of AISI 1045 with the goal of developing an experimental model to predict cutting force and surface roughness. Abbas et al. [13,14] utilized Response Surface Methodology (RSM) optimization in the turning of AISI 1045 steel to investigate the impact on surface roughness. Research has also been conducted on the tribological behavior, friction coefficient, and surface roughness in the machining of AISI 1045 steel. These studies have compared the use of vegeTable oils as lubricants with mineral oils to evaluate their respective impacts on the machining process [12-16].

Despite numerous studies on machining steels, particularly AISI 1045 steel [17-21], to the best of the authors’ knowledge, the use of cryogenic coolant R410A and its comparison with water-soluble cutting oil (WSCO) fluid have not been observed in any study. The process variables included cutting speed (four levels), cutting depth (three levels), and feed rate (three levels), and the measurement parameters were extensively and precisely conducted in three categories: tool wear, dimensional deviation, and surface roughness. Such a comprehensive volume of measurements is exceedingly rare in the literature. Statistical methods were employed for modeling and predicting the experimental outcomes.[17,19,22]

In this research, a new approach was taken to use the R410a coolant that was previously used in cooling systems of buildings and refrigerators and has the ability to reduce temperature up to -50 °C at the application site. This coolant was used as a cooling fluid for HSS tool during turning of AISI 1045 steel and by designing experimental tests, separate application of Water Soluble Cutting Oil (WSCO) fluid and R410a coolant jet on the cutting edge of HSS tool during turning was performed and tool wear and surface roughness resulting under both cooling conditions were investigated and compared.[20,22].

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2. Materials and Methods

Pieces of AISI1045 steel in the form of rods with an initial diameter of 50 mm were selected for testing. The hardness of the workpiece was 170 Vickers Hardness(HV).The pieces were cut into lengths of 350 mm and one side of them was drilled with a center drill. In each step, the pieces were placed inside the chuck by 40 mm and held by the centering device on the opposite side. The tools were made of HSS steel with dimensions of 12 by 12, under a chip angle of 14 degrees and front and side clearance angles of 8 degrees were ground and prepared.

The R410a coolant gas is a mixture of 50% difluoromethane (32R) refrigerant gas and 50% pentafluoroethane (125R) refrigerant gas. This gas is completely colorless, non-toxic, non-flammable and environmentally friendly.

A Tabriz50 TN lathe equipped with two stepper motors and gearboxes for controlling support movements electronically and equipped with a three-phase AC inverter to bring machine speed to accurate test values was used. A CNC Emco microscope camera was used to check the condition of the tool tip and Phertometer P1 roughness meter installed on the support set was used. By making some changes on Tabriz 50TN lathe machine, possibility of measuring dimensional deviation parameter and surface roughness (Ra) was provided. These changes are:

- Using two stepper motors and two drives for them and connecting them to computer system and installing motors on crosswise and longitudinal support to control machine axes by computer
- Using a three-phase inverter to achieve accurate cutting speed and cutting speed control from behind spindle by digital tachometer (Fig. 1.a)
- Installing a camera on Emco CNC lathe microscope and installing this set on lathe tool holder (Fig. 1.b)
- Installing WSCO nozzle on tool holder and connecting it to pump and WSCO tank
- Installing nozzle for applying R410a coolant fluid and connecting it to capsule containing fluid (Fig. 1.c, d)
- Installing digital measuring clock holder base on support set to measure workpiece diameter at different stages (Fig. 1.e)
- Installing roughness meter Phertometer holder base on support set to measure workpiece surface roughness (Fig. 1.f)

Finally, after preparing prerequisites for research, by considering different cutting speeds and different cutting depths and different automatic feeds, tool wear rate, surface roughness (Ra) and dimensional deviation were recorded. Fig. 1. (g) and (h) show recording and processing camera image.

In this research, some changes were applied to Tabriz 50 TN lathe at the beginning. These changes included adding two stepper motors (8.1 degrees and 4.5 kN) and a gearbox (with a transmission ratio of 1:50) at the input of longitudinal and crosswise support and adding a three-phase inverter at the input of electric motor of the machine and a speed encoder along the axis of the chuck, to adjust the machine speed.

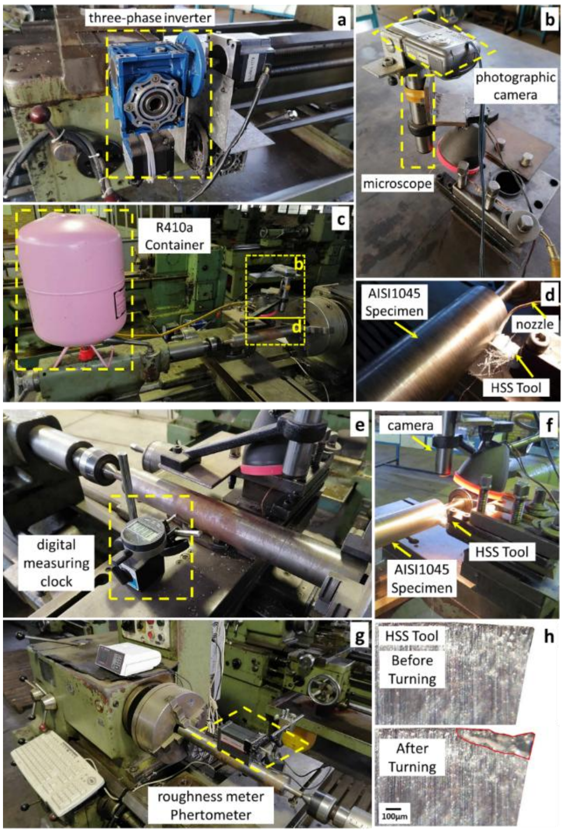

Fig. 1. (a) Installing three-phase inverter, (b) Installing a photographic camera on a microscope placed on a lathe, (c) and (d) Installing nozzle for applying R410a coolant fluid.contiued. (e) Installing digital measuring clock holder base, (f) Installing roughness meter Phertometer holder base, (g) and (h) Recording and processing camera image.

The stepper motors used in the machine (model 86 MG) were connected to a computer system by using two Leadshine (model DM542E) stepper motor drives through LPT port to make machine movements controllable by numerical control mechanism. Also, the encoder used was connected to the computer by the mentioned port and adjusted the required speed for the machine by using the inverter connected to the electric motor. The software used in the computer system was Mach3 version (R3.043.066), which provided the required pulses for stepper motor drives and inverter through LPT port.

In addition to the motion equipment added to Tabriz 50 TN lathe, a microscope for displaying tool tip of CNC Emco machine was installed on tool holder of the machine by a fixture made, and images were stored by a Samsung digital camera with 5 megapixel quality (Fig. 1g, h). Another fixture designed had the task of carrying roughness meter .

The WSCO and R410a fluid nozzles were also installed on tool holder set and adjusted on tool tip to apply accurately. WSCO fluid was controlled by WSCO pump and R410a fluid was applied to tool by an electric valve that was controlled by computer system. WSCO fluid tank was located in standard place and under lathe machine and R410a fluid tank was aligned with nozzle and located on centering device. WSCO fluid is applied by pump but R410a fluid is applied only by opening electric valve due to high pressure of tank.The prepared samples were subjected to turning operation after being clamped inside chuck.

Turning operation started from beginning of piece and simultaneously, timer started counting minutes and operation continued for 60 min. In this stage, if before reaching length of 300 mm time ended, measurement was done at related length and according to time intervals of 5 min. at position that tool had measurement in mentioned time intervals and if despite reaching end of path of 300 mm time had not ended; tool returned to beginning of path and operation continued until reaching time of 60 min. It should be noted that in such case, tool without grinding should continue machining until completion of time. In each stage of turning cycle, type of cooling fluid, cutting speed, feed rate and cutting depth were specified and fixed.

Also data related to tool wear amount, surface roughness and dimensional deviation were measured and recorded by camera microscope of CNC Emco machine in desired time ranges from measurement model. In this way, in each cycle of turning at 5 min. times (up to 60 min.) for tool wear amount, surface roughness and dimensional deviation measurement and recording were done. To measure tool wear in rake side, images recorded by digital camera installed on CNC Emco machine microscope were transferred to computer and analyzed by Digimizer software. Fig.1.(h) shows an example of images analyzed in Digimizer software. At end of operation, sample diameter from beginning to end of path of 300 mm at intervals of 50 mm was measured by Mitutoyo digital micrometer and checked by digital measuring clock model 12A and recorded. In this way, in each cycle of turning 6 numbers for diameters and 6 numbers for diameter difference compared to initial diameter were calculated and recorded.

Considering that the desired cutting speed is specified in each stage, the speed was calculated according to the diameter reduction in each stage and corrected in the written G-Codes. The data related to surface roughness were measured and recorded by Phertometer p1 roughness meter in the desired time ranges from the measurement model. In this way, in each test cycle, 12 numbers for surface roughness were measured and recorded for 60 min. divided into 5 min. times. Considering that the desired cutting speed is specified in each stage, the speed was calculated like the previous test according to the diameter reduction in each stage and corrected in the written G-Codes .

The cutting speeds considered for the test were 15, 25, 40 and 55 m/min, cutting depth of 0.5, 1 and 1.5 mm and feed rates of 0.05, 0.12 and 0.2 mm/rev. Table 1 shows the input parameters and their levels. All parameters were recorded for one stage for WSCO fluid and another stage for R410a fluid. Fig. 2. shows the flowchart of lathe and workpiece preparation and the process of tests.

Table. 1. The input parameters and their levels.

Parameter	Unit	Level 1	Level 2	Level 3	Level 4
Cutting speed	m/min	15	25	40	55
Depth of Cut	mm	0.5	1	1.5	-
Feed Rate	mm/rev.	0.05	0.12	0.2	-

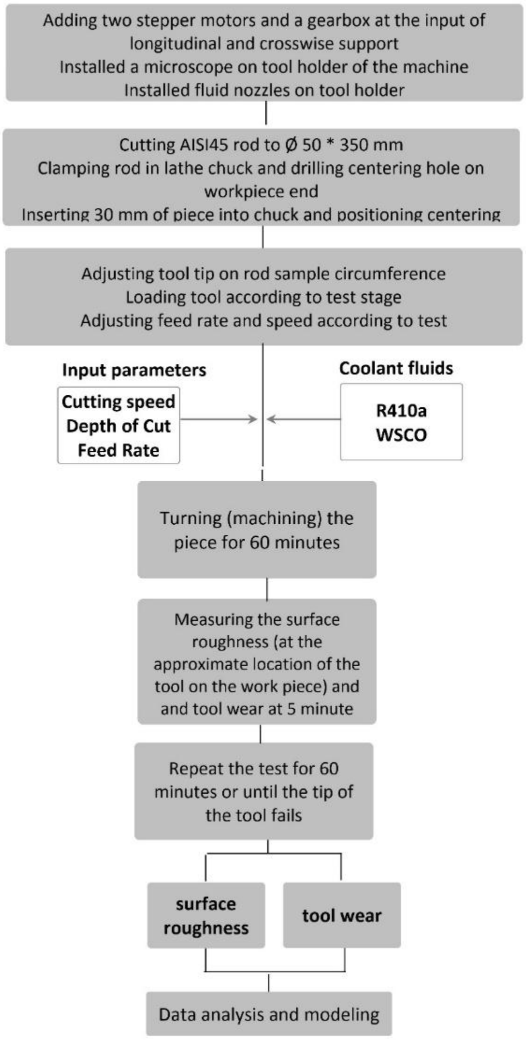

Fig. 2. Flowchart of preparation of lathe and work piece and process of tests.

3. Results and Discussion

3.1. Data Analysis for Surface Roughness

To save consumable materials, recording data related to surface roughness in some tests was measured simultaneously with recording data related to dimensional deviation. Since in recording data related to dimensional deviation, a length of 300 mm was used as the basis from the beginning to the end of the test process and in recording data related to surface roughness, a time of 60 min. was used as the basis of investigation, the test duration for these two cases was different. Therefore, according to different cutting speeds, the tool course covered for different cases was not the same. In following Tables for four cutting speeds, three cutting depths and three feed rates for tool considered and surface roughness at 5 min. intervals up to final time of 60 min. was recorded. In Fig. 3., lack of curve continuation means complete failure of tool cutting edge at that specific time. Table. 2. shows surface roughness of pieces after passing time of 60 min. or time of tool tip failure for two coolants.

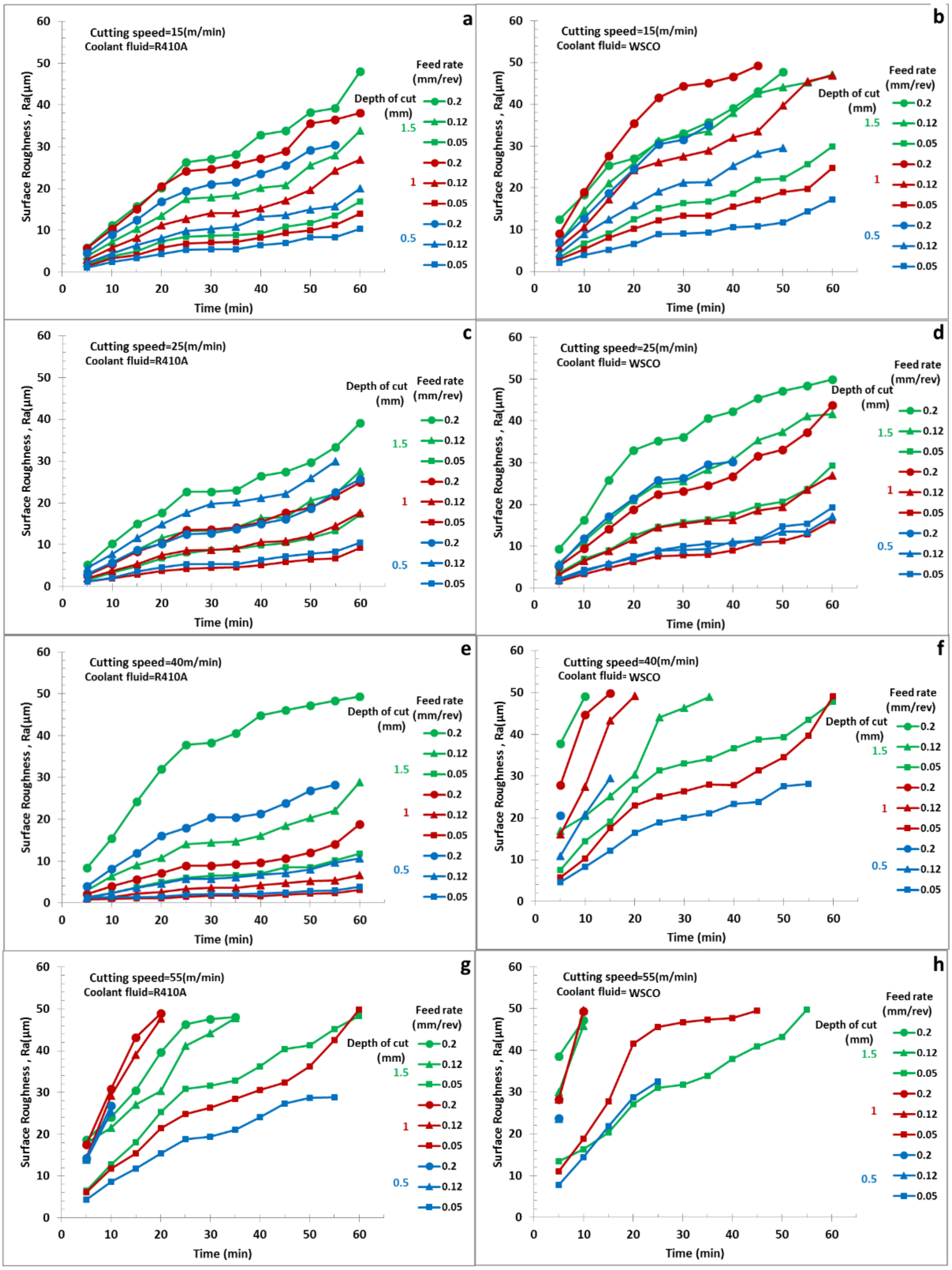

Fig. 3. The surface roughness changes based on chip removal time for two coolants; ; (a,c,e,g) R410a coolant and (b,d,f,h) WSCO coolant; cutting speed from top to bottom respectively 15, 25, 40 and 55 m/min, cutting depth and feed rate inside each diagram are indicated by different color and shape.

Table. 2. Tool wear and surface roughness after passing time of 60 min. or the time of tool tip failure (which is indicated by red colour) for WSCO and R410a coolants.

Row	Cutting speed (m/min)	Depth of cut (mm)	Feed rate (mm/rev)	Surface Roughness(µm)		Tool wear(µm)	
				WSCO	R410a	WSCO	R410a
1	15	0.5	0.05	17.2	10.3	124	73
2	15	0.5	0.12	🟥 29.5	20	🟥 231	150
3	15	0.5	0.2	🟥 34.9	🟥 30.5	🟥 250	🟥 228
4	15	1	0.05	24.8	14	185	97
5	15	1	0.12	46.9	26.9	410	190
6	15	1	0.2	🟥 49.3	38.1	🟥 467	375
7	15	1.5	0.05	29.9	16.9	235	119
8	15	1.5	0.12	47.1	33.9	510	255
9	15	1.5	0.2	🟥 47.7	48	🟥 595	400
10	25	0.5	0.05	19.2	10.5	140	73
11	25	0.5	0.12	17.1	🟥 30	🟥 224	130
12	25	0.5	0.2	🟥 30.2	25.7	🟥 237	195
13	25	1	0.05	16.1	9.2	110	60
14	25	1	0.12	26.9	17.7	210	125
15	25	1	0.2	43.8	25	350	190
16	25	1.5	0.05	29.3	17.1	230	117
17	25	1.5	0.12	41.6	27.6	400	200
18	25	1.5	0.2	49.9	39.1	650	350
19	40	0.5	0.05	🟥 28.1	3.9	🟥 220	25
20	40	0.5	0.12	🟥 29.5	10.7	🟥 215	78
21	40	0.5	0.2	🟥 20.6	🟥 28.2	🟥 158	🟥 223
22	40	1	0.05	49.1	3.1	400	20
23	40	1	0.12	🟥 49.2	6.6	🟥 414	45
24	40	1	0.2	🟥 49.8	18.8	🟥 690	130
25	40	1.5	0.05	47.8	11.8	500	85
26	40	1.5	0.12	🟥 49	28.9	🟥 700	210
27	40	1.5	0.2	🟥 49.1	49.3	🟥 555	600
28	55	0.5	0.05	🟥 32.5	🟥 28.8	🟥 250	🟥 225
29	55	0.5	0.12	🟥 23.6	🟥 25.3	🟥 174	🟥 183
30	55	0.5	0.2	🟥 23.7	🟥 26.8	🟥 175	🟥 204
31	55	1	0.05	🟥 49.5	49.8	🟥 455	400
32	55	1	0.12	🟥 49.6	🟥 47.7	435	🟥 444
33	55	1	0.2	🟥 49.3	🟥 48.9	446	🟥 480
34	55	1.5	0.05	🟥 49.7	48.3	667	475
35	55	1.5	0.12	🟥 45.8	🟥 47.8	513	🟥 710
36	55	1.5	0.2	🟥 47.2	🟥 48.1	565	🟥 700

In data analysis of test, general full factorial was used to investigate effect of cutting speed, feed rate and cutting depth on dimensional deviation.

Generally, in all cases, the surface roughness increases with increasing cutting depth and feed rate. In R410a coolant, the lowest surface roughness of 3.1 µm is related to 40-1-0.05 (Fig. 3.e) and the highest of 49.8 µm belongs to 55-1-0.05(Fig. 3.g). On the other hand, in WSCO fluid, the surface roughness increases exponentially over time with increasing cutting speed in all cases. The lowest and highest surface roughnessin WSCO fluid with values of 16.1 and 49.9 µmrespectively belong to conditions of 25-1-0.05 and 25-1.5-0.2(Fig. 3.d). The high amount of surface roughness, especially at high cutting speeds and high cutting depths, is due to the formation of a hardened built-up edge at the tool cutting edge at the beginning of the tool entry into the workpiece and the lack of opportunity to separate it at the initial times of chip removal.

This issue is confirmed by recorded images. In addition, the better performance of R410a fluid is evident.The ANOVA for surface roughness for R410a coolant fluid is shown in Table. 3. According to the confidence level of 95%, the value P of the model is less than 0.05, which indicates a good fit of the model with experimental results. The value R2 in the ANOVA Table is almost 91%, which indicates the coverage of data by the analysis done and the equations obtained.

According to the ANOVA done in Table. 3., the effects of feed rate, cutting speed and cutting depth on surface roughness are respectively 37.15%, 32.82% and 20.79%, and the accuracy of analysis is 90.75%. In addition to the separate effect of each parameter, the simultaneous effect of parameters was also investigated. In the Pareto chart, it is also observed that all three factors are effective.The values of coefficients of linear equation were calculated. The specifications of these coefficients are given in Table. 4. Fig. 4. shows the calculated values through fitted model along with experimental values for surface roughness. The data distribution in Figs. 4. And 5. shows that the proposed model can predict the surface roughness accurately.

Table. 3. ANOVA for surface roughness in R410a coolant fluid.

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Model	7	4881.7	90.75%	4881.7	697.39	25.24	0.0
Linear	7	4881.7	90.75%	4881.7	697.39	25.24	0.0
Cutting speed(m/min)	3	1765.3	32.82%	2406.0	801.99	29.03	0.0
Depth of cut(mm)	2	1118.4	20.79%	816.8	408.38	14.78	0.0
Feed rate(mm/rev)	2	1998.1	37.15%	1998.1	999.04	36.16	0.0
Error	18	497.3	9.25%	497.3	27.63		
Total	25	5379.1	100.00%				
			S	**R-sq**	**R-sq(adj)**	**PRESS**	**R-sq(pred)**
			5.25636	90.75%	87.16%	1213.85	77.43%

Table. 4. The coefficients of linear equation for surface roughness in R410a coolant fluid.

Term	Coef	SE Coef	95% CI	T-Value	P-Value	VIF
Constant	30.80	1.38	(27.90, 33.70)	22.34	0.0	
Cutting speed (*CS*)(m/min)						
15	-3.85	1.85	(-7.73, 0.03)	-2.08	0.052	1.06
25	-9.98	1.86	(-13.89, -6.07)	-5.36	0.0	1.08
40	-13.22	1.85	(-17.10, -9.34)	-7.16	0.0	1.06
55	27.06	3.15	(20.45, 33.67)	8.60	0.0	*
Depth of cut (*DC*)(mm)						
0.5	-4.44	1.68	(-7.96, -0.91)	-2.64	0.017	1.57
1.0	-3.37	1.44	(-6.40, -0.33)	-2.33	0.032	1.51
1.5	7.80	1.44	(4.77, 10.84)	5.40	0.0	*
Feed rate (*FR*)(mm/rev)						
0.05	-11.03	1.50	(-14.17, -7.88)	-7.37	0.0	1.41
0.12	-0.92	1.53	(-4.14, 2.31)	-0.60	0.557	1.28
0.20	11.95	1.61	(8.57, 15.32)	7.43	0.0	*

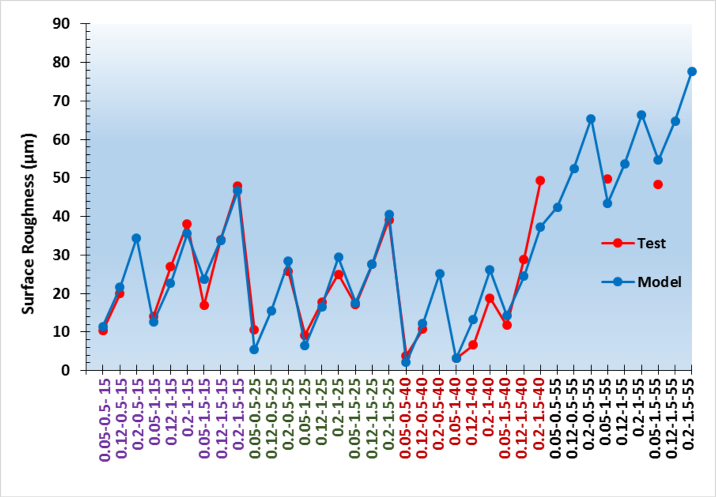

Fig. 4. Comparison of experimental surface roughness results and predicted values using model.

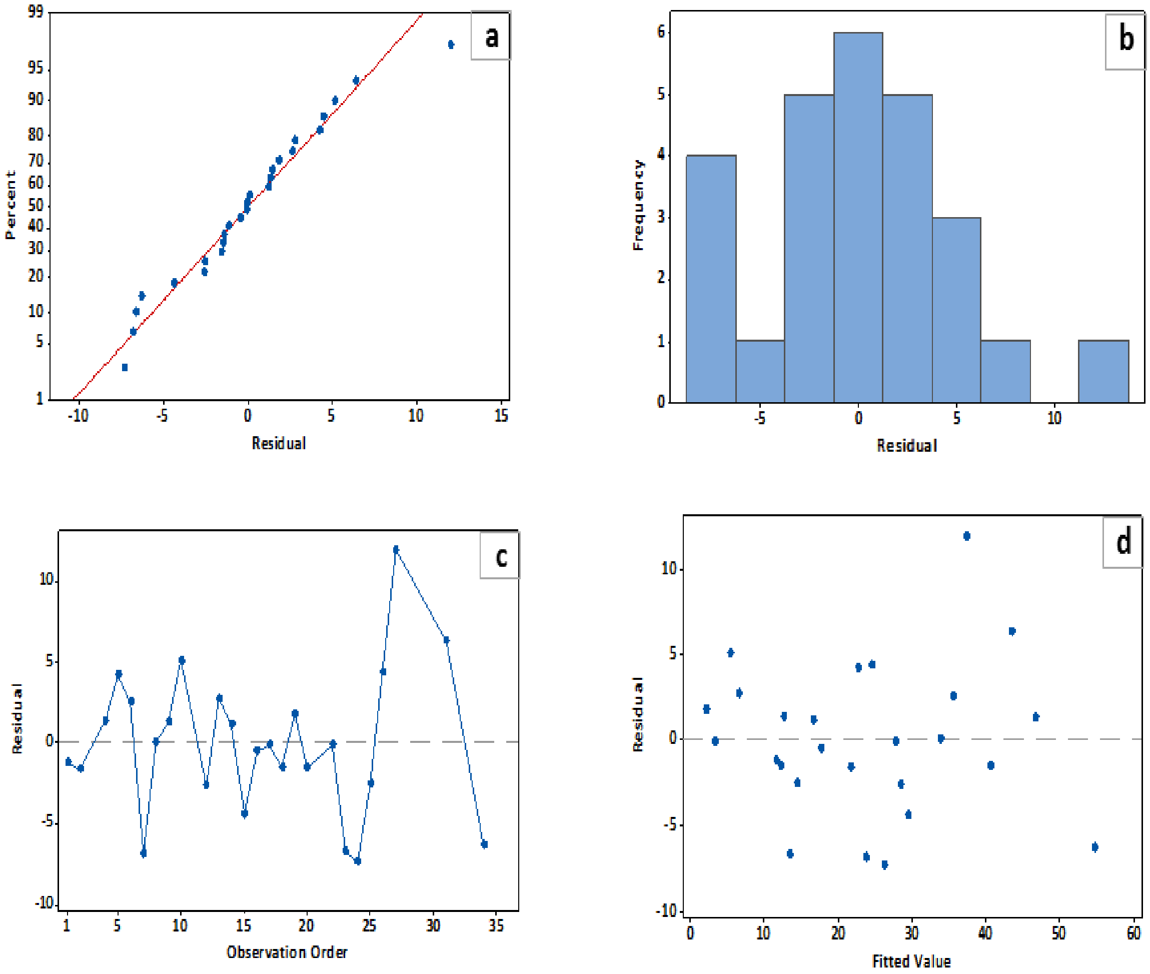

Fig. 5. Comparison of experimental surface roughness results and predicted values using model, (a) Normal probability distribution chart of residuals, (b) residuals versus values obtained from model,(c) residuals versus test numbers, (d) residuals versus fitted values for R410a coolant fluid.

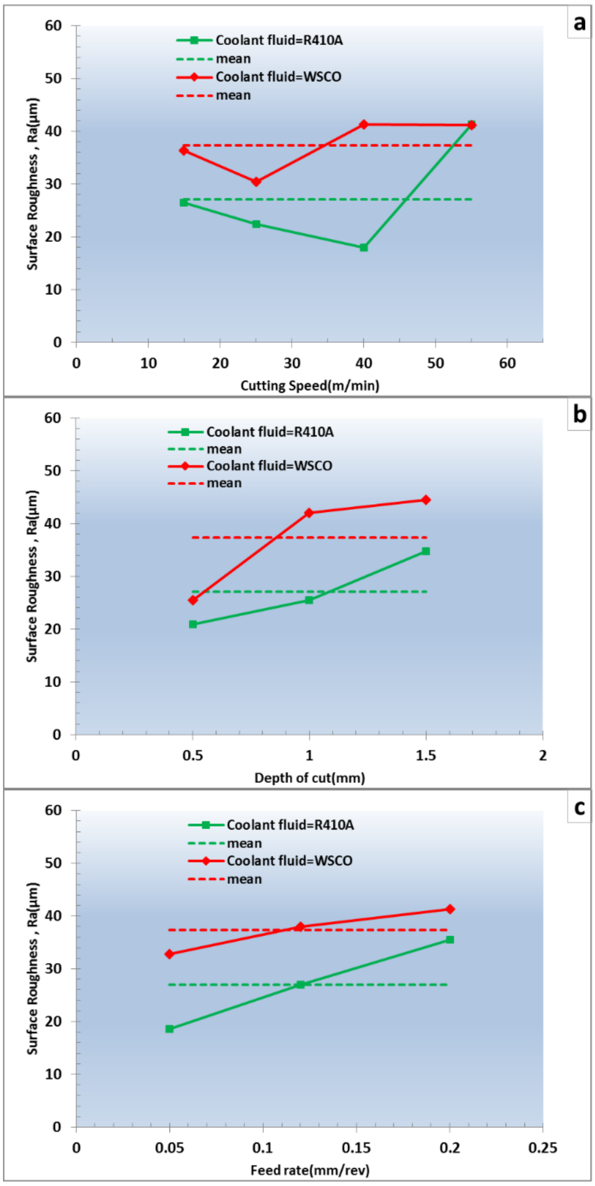

Fig.6. The statistical analysis of surface roughness results for two coolants; (a)cutting speed, (b) cutting depth and (c)feed rate; green color for R410a coolant and red color for WSCO coolant.

The regression equation of surface roughness in R410a coolant fluid based on Table 4 is as follows:

Surface Roughness, R410a(µm) = 30.80 - 3.85 CS15- 9.98 CS25- 13.22 CS40+ 27.06 CS55 - 4.44 DC0.5- 3.37 DC1.0+ 7.80 DC1.5- 11.03 FR0.05 - 0.92 FR0.12+ 11.95 FR0.20

In Fig.6., the main effects of means on surface roughness are shown. It is observed that in total, the average surface roughness with R410a coolant is 27 µm, which is 37% less than that with WSCO coolant (37 µm). In Fig.6.(a), in both coolants, the minimum surface roughness is observed with changing cutting speeds, which are for R410a and WSCO coolants at speeds of 40 and 25 m/min, respectively. On the other hand, with increasing cutting depth and feed rate in both coolants, the surface roughness value increases. In Fig.6.(b), with increasing cutting depth from 0.5 to 1 mm, the surface roughness value in R410a coolant is less than that in WSCO and after that, the rate of surface roughness increase in R410a coolant is more than that in WSCO. In Fig.6.(c), with increasing feed rate from 0.05 to 0.12 and then to 0.2 mm/rev., the rate of surface roughness increase in R410a coolant is more than that in WSCO. At high cutting speeds, the growth of surface roughness value in both WSCO and R410a fluids is noticeable, which is due to tool wear and in several cases, the final surface roughness value at 60 min. time especially for WSCO fluid due to failure of tool cutting edge was not measurable.Based on data optimization through software, for WSCO coolant fluid, the lowest surface roughness is obtained at a cutting speed of 25 m/min, a feed rate of 0.05 mm/rev., and a cutting depth of 0.5 mm. According to the diagram, the lowest surface roughness for R410a coolant fluid occurs at a cutting speed of 40 m/min, a feed rate of 0.05 mm/rev., and a cutting depth of 0.5 mm.

3.3. Data Analysis for Tool Wear

In Fig.7., results for four cutting speeds, three different cutting depths and three tool feed rates and tool wear values at 5 min. intervals up to final time of 60 min. (12 stages) are recorded.

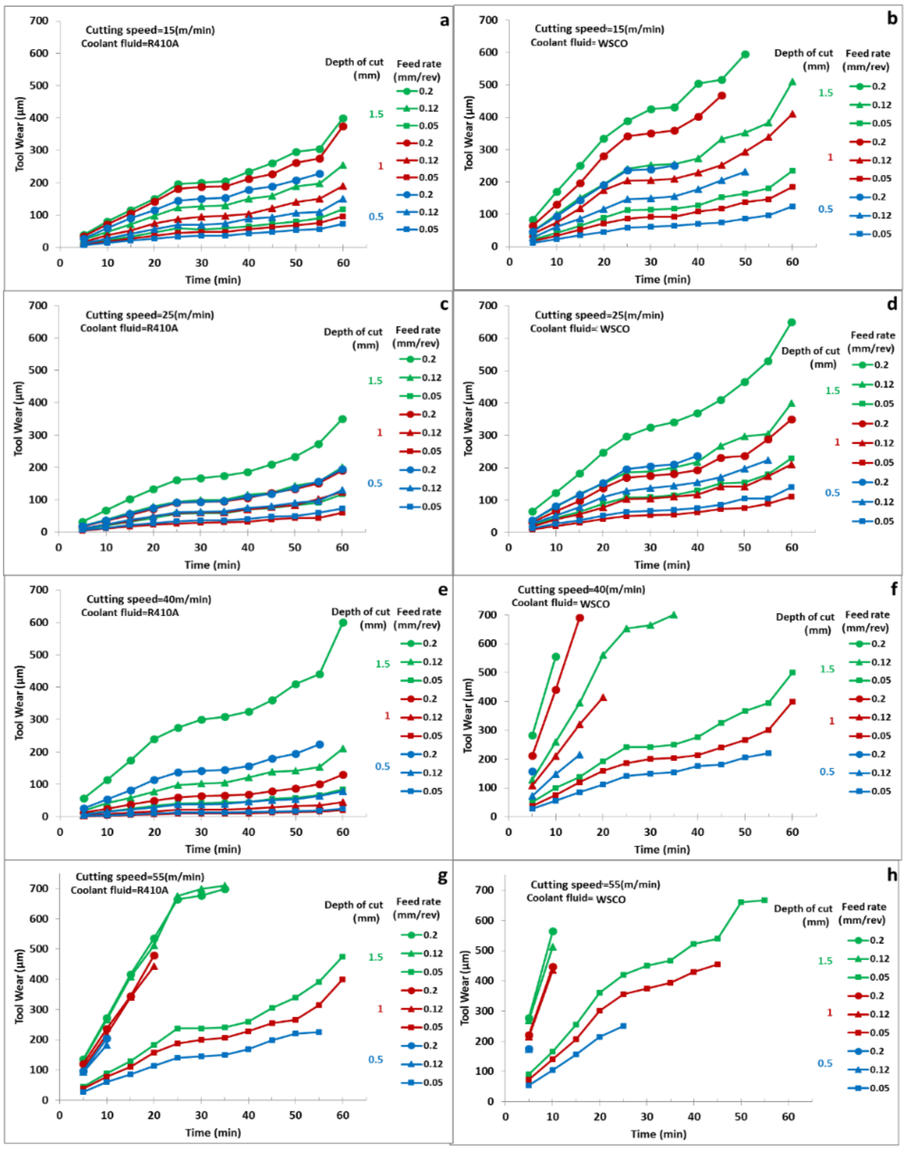

Fig.7. Tool wear changes based on chip removal time for two coolants; (a,c,e,g) R410a coolant and (b,d,f,h) WSCO coolant; cutting speed from top to bottom respectively 15, 25, 40 and 55 m/min, cutting depth and feed rate inside each diagram are indicated by different color and shape.

Table. 5. The ANOVA for tool wear in R410a coolant fluid.

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Model	7	477449	82.45%	477449	68207	12.75	0.0
Linear	7	477449	82.45%	477449	68207	12.75	0.0
Cutting speed(m/min)	3	146343	25.27%	205354	68451	12.80	0.0
Depth of cut(mm)	2	113494	19.60%	83542	41771	7.81	0.003
Feed rate(mm/rev)	2	217612	37.58%	217612	108806	20.34	0.0
Error	19	101641	17.55%	101641	5350	-	-
Total	26	579090	100.00%	-	-	-	-
			S	**R-sq**	**R-sq(adj)**	**PRESS**	**R-sq(pred)**
			73.1406	82.45%	75.98%	201817	65.15%

Table. 6. The coefficients of linear equation for tool wear in R410a coolant fluid.

Term	Coef	SE Coef	95% CI	T-Value	P-Value	VIF
Constant	266.5	18.7	(227.4, 305.5)	14.28	0.0	
Cutting speed (*CS*)(m/min)						
15	-47.1	25.4	(-100.2, 6.1)	-1.85	0.080	1.05
25	-106.5	25.4	(-159.7, -53.3)	-4.19	0.0	1.11
40	-105.3	25.4	(-158.5, -52.1)	-4.15	0.001	1.05
55	258.9	43.7	(167.4, 350.3)	5.93	0.0	*
Depth of cut (*DC*)(mm)						
0.5	-36.1	22.3	(-82.6, 10.5)	-1.62	0.122	1.54
1.0	-40.9	19.8	(-82.3, 0.5)	-2.07	0.052	1.46
1.5	77.0	19.8	(35.6, 118.4)	3.89	0.001	*
Feed rate (*FR*)(mm/rev)						
0.05	-105.9	20.5	(-148.8, -62.9)	-5.16	0.0	1.37
0.12	-26.5	20.5	(-69.5, 16.4)	-1.29	0.212	1.25
0.20	132.4	22.3	(85.8, 179.0)	5.95	0.0	*

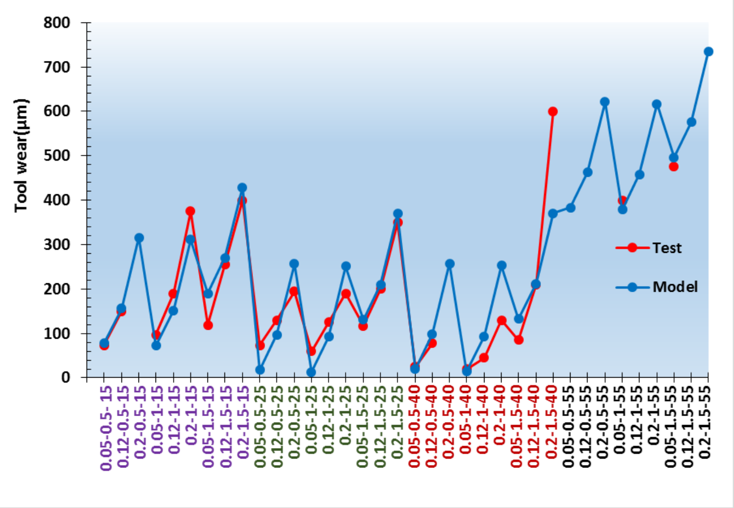

Fig. 8. Comparison of experimental tool wear results and predicted values using model.

The regression equation of tool wear in R410a coolant fluid based on Table 8 is as follows:

Tool wear, R410a(µm) = 266.5 – 47.1 CS15- 106.5 CS25- 105.3 CS40+ 258.9 CS55 – 36.1 DC0.5- 40.9 DC1.0+ 77.0 DC1.5- 105.9 FR0.05 – 26.5 FR0.12+ 132.4 FR0.20

It is observed that tool wear using R410a coolant in all cases at a cutting speed of 15 m/min was measured below 400 µm (Fig.7.a). The same condition exists at cutting speeds of 25 and 40 m/min (except at a cutting depth of 1.5 mm and a feed rate of 0.2 mm/rev.)(Fig.7.c, Fig. 7.e). On the other hand, in WSCO fluid with increasing cutting speed in all cases, tool wear rate increases exponentially over time and even in some cases (cutting speed of 55 and40 m/min and cutting depth of 0.5 mm and feed rate of 0.2 mm/rev.; also, cutting speed of 55 m/min and cutting depth of 0.5 mm and feed rate of 0.12 mm/rev.)(Fig.7.f, Fig. 7.h) tool lost its efficiency in first 5 min. Tool in WSCO coolant at cutting speeds of 15, 25, 40 and 50 m/min respectively disappeared in 4, 2, 7 and 9 cases and did not have efficiency up to 60 min. While in R410a this issue occurred in only one case at each speed except for 50 m/min where it occurred in seven cases. In R410a coolant lowest and highest tool wear rate respectively are equal to 0.33 and 24 µm/min respectively for 40-1-0.05 and 55-1-0.2 and in WSCO coolant lowest and highest tool wear rate respectively are equal to 1.83 and 56.5 µm/min for 25-1-0.05 and 55-1.5-0.2. The ANOVA for tool wear in R410a coolant fluid is shown in Table 5. According to the confidence level of 95%, the value P of the model is less than 0.05, which indicates a good fit of the model with experimental results. The value R2 in the ANOVA Table is almost 82.5%, which indicates the coverage of data by the analysis done and the equations obtained.

According to the ANOVA done in Table. 5., the effects of feed rate, cutting speed and cutting depth on tool wear are respectively 37.58%, 25.27%, and 19.60%, and the accuracy of analysis is 82.45%.

In addition to the separate effect of each parameter, the simultaneous effect of the parameters was also investigated. In the Pareto chart, it is also observed that all three factors are influential.

The values of the coefficients of the linear equation were calculated. The specifications of these coefficients are given in Table. 6. Fig.8. shows the calculated values from the fitted model along with the experimental values for tool wear. The results calculated from the mathematical model are in good agreement with the experimental results. The data in Fig.9. are scattered around a normal distribution, which indicates that the errors are random and the fitted model has a high quality.

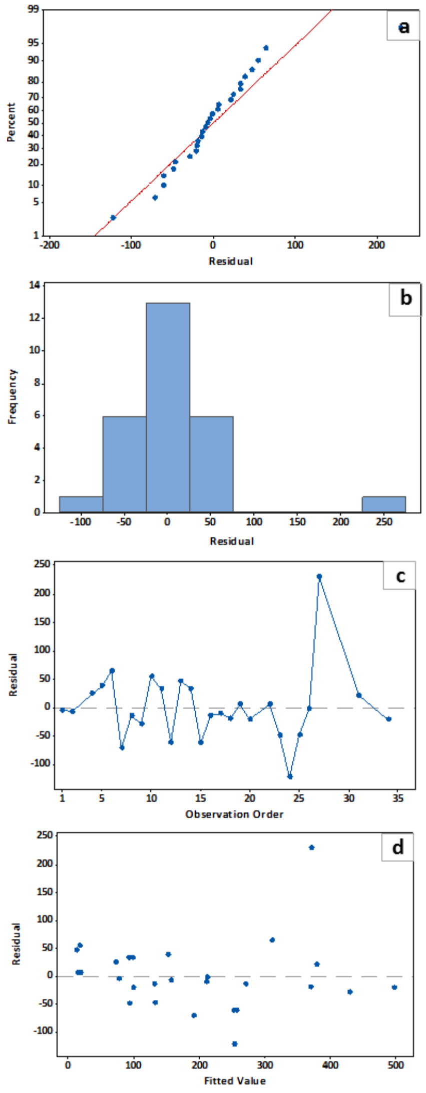

Fig. 9. Comparison of experimental tool wear results and predicted values using model, (a) Normal probability distribution chart of residuals, (b) residuals versus values obtained from model,(c) residuals versus test numbers, (d) residuals versus fitted values for R410a coolant fluid.

In Fig.10., the main effects of means on tool wear are shown. It is observed that in total, the average tool wear with R410a coolant is 238 µm, which is 35% less than that with WSCO coolant (364 µm). In Fig.10.(a), in both coolants, the minimum tool wear is observed with changing cutting speeds, which are for R410a and WSCO coolants respectively at speeds of 40 and 25 m/min. On the other hand, with increasing cutting depth and feed rate in both coolants, the tool wear value increases. In Fig.10.(b), with increasing cutting depth from 0.5 to 1 mm, the tool wear value in R410a coolant is less than that in WSCO and after that, the rate of tool wear increase in both coolants is almost equal. In Fig.10.(c), with increasing feed rate from 0.05 to 0.12 mm/rev., the rate of tool wear increase in both coolants is almost parallel to each other and after that, while tool wear in R410a coolant increases linearly, this change in WSCO coolant is slightly decreasing. At high cutting speeds, the growth of tool wear value in both WSCO and R410a fluids is noticeable, which is due to tool built-up edge and in several cases, the final tool wear value at 60 min. time especially for WSCO fluid due to failure of tool cutting edge was not measurable.

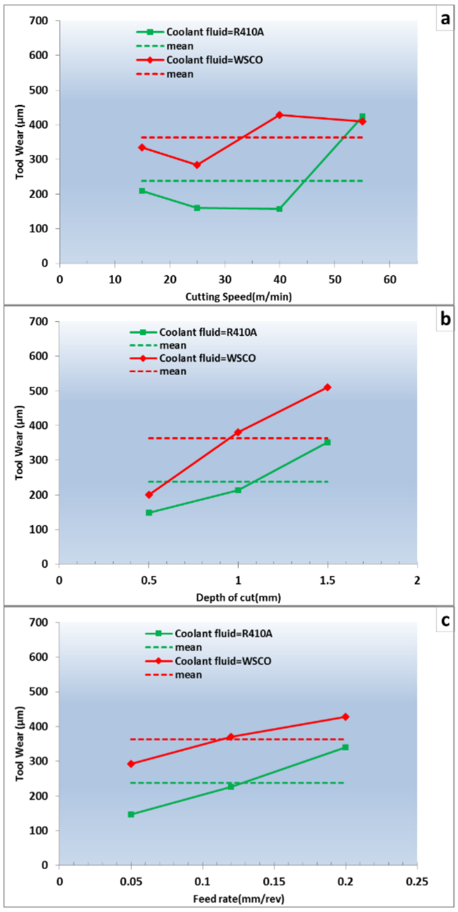

Fig. 10. The statistical analysis of tool wear results for two coolants; (a)cutting speed, (b) cutting depth and (c)feed rate; green color for R410a coolant and red color for WSCO coolant.

Based on data optimization through software, for WSCO coolant fluid, lowest tool wear at a cutting speed of 25 m/min, a feed rate of 0.05 mm/rev., and a cutting depth of 1 mm is obtained. According to diagram, lowest tool wear for R410a coolant fluid at a cutting speed of 40 m/min, a feed rate of 0.05 mm/rev., and a cutting depth of 1 mm occurs.

4.Conclusion

This study examined the impact of cutting speed, depth, and feed rate on tool wear and surface roughness when turning AISI 1045 steel with an HSS tool, comparing conventional WSCO and R410a coolants. Key findings include:

1. R410a outperformed WSCO, reducing average surface roughness by 37% (27 µm vs. 37 µm) and tool wear by 35% (238 µm vs. 364 µm).
2. Lower wear rate (0.33 µm/min) with R410a allowed successful turning at 40–55 m/min, whereas WSCO caused tool failure at these speeds.
3. ANOVA revealed feed rate, cutting speed, and depth as the most influential factors on tool wear and surface roughness,respectively.
4. Optimal results with R410a (20 µm tool wear, 3.1 µm roughness at 40-1-0.05 conditions) were significantly better than WSCO's minima (400 µm, 16.1 µm).Best performance occurred at 40 m/min with R410a versus 25 m/min with WSCO.
5. R410a enabled a 60% higher cutting speed (25 → 40 m/min), reducing tool wear 20-fold and roughness 10-fold, while improving machining quality and dimensional accuracy due to superior cooling.
6. As the Material Removal Rate (MRR) , determined by cutting speed, depth, and feed rate, increases, tool wear, dimensional deviation, and surface roughness also rise. However, when using R410a coolant, these parameters increase at about one-third the rate compared to WSCO coolant.

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