JJMIE

Volume 12, Number 3, October. 2018
ISSN 1995-6665
Pages 161 - 166

Jordan Journal of Mechanical and Industrial Engineering

Olive Mill Wastewater as Cutting Fluids: Effect on Surface Roughness of Aluminum

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Received 8 Apr. 2018

Abstract

In this experimental work, the use of olive mills' wastewater (OMW) as a cutting fluid in machining processes has been investigated. The experiments were performed on the most two common metal removing processes, namely turning and milling with the use of the proposed cutting fluid. In this present study, the performances of OMW were compared with that of mineral oil-based cutting fluid and dry conditions during the machining operation of Aluminum alloy. The effect of OMW as cutting fluid on the surface roughness of Aluminum alloy has been studied. The experiment involved the use of different parameters such as cutting speed, depth of cut and feed rate. The values of the measured surface roughness found to be in the range of good performance for turning and milling (Ra = 0.4- 2.5 micron). Ra is the submicron size for good operation parameters (specifically when Depth of cut is less than 0.5 mm and spindle speed is more than 2200 rpm). The results of this work compared with different theoretical models from works of literature have been found to be in agreement with them. The proposed fluid worked very well as a cutting fluid. Based on these results, OMW is being recommended as viable alternative lubricants to the mineral oil during machining. More investigations need to be done to check the safety measures and chemical hazards of using it.

Keywords: Cutting Fluid, Surface Roughness, Cutting speed, Feed, Depth of cut, Olive mill wastewater (OMW);

1. Introduction

Although Jordan ranks as the eighth largest olive oil producing country in the world, it still lacks proper facilities for the treatment of OMW (or Zibar as locally called), an oily waste generated during the olive oil extraction process [1]. Jordan has more than 15 million olive trees that produce over 130,000 tons of olives, 85 percent of which farmers send to the 128 olive presses spread across the country. Seventy percent of the mills are in the northern region. In 2012, the country's olive mills produced 212,418 cubic meters of zibar, which resulted from the processing of 115,282 tons of olives [1] and more detail for the northern part of Jordan can be found in Table 1 [2].

OMW is black or reddish black, with a strong offensive smell, a high percentage of fat, oil, and grease as well as a high organic load, which is 400 times higher than that of domestic wastewater. A remarkable study [1], warned from the disposal OMW. If it spreads on soil or is dumped in valleys, OMW (zibar) can cause serious environmental problems and reduce soil fertility as it contains many chemicals. The authors of this study [1] presented several recommendations to manage the disposal of zibar, including the establishment of an olive oil wastewater treatment plant and evaporation ponds to serve all the presses across the country. One potential solution is to use OMW in irrigation. The effect of it on soil properties, olive tree performance, and oil quality had been studied [3]. They found that if it used in a controlled way it will with no negative effects. The ratio of dilution had been studied and from the data obtained, it is suggested that 1:20 OMW dilutions are still phytotoxic and that higher OMW dilutions should be used in order to use this waste for the irrigation of spinach plants [4]. Another study in Italy is to use OMW in the vermicomposting process. The results obtained from the photo-test showed that the OMW lose their toxicity and stimulate plant germination and growth [5]. One more application may be in the pharmaceutical industry by separation of polyphenols from Jordanian OMW [6]. A Review of the technologies for OMW treatment presented in the literature [7]. A more recent comprehensive review of OMW components extraction and management were present in reference [8]. In that work, the state of the art of OMW management was presented, with a focus on physicochemical processes, either alone or in combination, varying in complexity, ease of operation, and associated costs. Until now there has not been a defined management strategy that can be adopted

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on a global scale that is feasible in different socio-economic contexts and production scales. A plethora of reclamation practices, as well as combined treatments for OMW, have already been proposed and developed but have not led to completely satisfactory results[Details can be found in 8].

On the other side, many researchers studied the use of different types of vegetable oils such as rapeseed, canola, and coconut oil as an alternative for mineral oil in cooling machining processes. Vegetable Oil-Based Cutting Fluids had been used as a cutting fluid in machining operations [9-13]. The results of these studies encouraged to using OMW, which is a similar material, as a cutting fluid and this is the aim of the current work.

Cutting fluid plays a major role in machining operations. These roles include making cutting easy, improving tool life, improving surface finish, flushing away chips from the cutting zone, increasing the rate of productivity, and alleviating the negative effect on work environment and operators. The cutting fluid contributes significantly toward machining cost and also possesses environmental threats. The cutting fluids of the future have to be more environmentally adapted, have a higher level of performance, and lower total life-cycle cost (LCC) than commonly used cutting fluid today. The properties of the base fluids must be identified in order to be able to formulate. They can be divided into three groups, i.e., physical, chemical, and film formation properties. The fluid is used as a coolant and also as lubricates of the cutting surfaces. The selection of cutting fluid should also include considerations such as its effects on, workpiece material and machine tools, biological considerations and the environment [14-16]. There are a few challenges associated with the use of OMW as cutting fluids. The aim of this work is to achieve better surface quality with low machining cost with new fluid. As the OMW is free of charge waste material, it has been used as a cutting fluid for different cutting machines.

Table1. Quantities of Zibar water (in cubic meters) produced in Jordan [2].

	Number of extraction mills	2008	2009	2010	2011	2012	2013	2014
Irbid	53	6338	6374	35554	14154	18454	12447	17830
Mafraq	12	1089	2748	1906	2843	2394	4915	5955
Jerash	15	3433	4138	17011	4486	5071	3945	4960
Ajloun	15	3429	4672	13486	8440	8044	7409	6981
Total	**95**	**14289**	**17932**	**67957**	**29923**	**33963**	**28716**	**35726**

2. MATERIALS & METHODS

2.1. Workpiece material

Aluminum and its alloys are used in a huge variety of products because of its special properties. It is non-toxic, and has low density and high thermal conductivity, and it also has excellent corrosion resistance, and can be easily cast, machined and formed. The composition as well as the physical, mechanical, electrical, thermal, and processing properties of Aluminum alloys can be found in the literature [e.g. 14]. For these reasons, low-cost aluminum alloy (5083) is used as workpiece material. The detail specification and composition of this alloy can be found in the open source through the internet.

2.2. The cutting fluid (OMW)

OMW **(Zibar)** is known as a liquid material "wastewater" black colored produced by pressing the olive into oil, and according to specialists; it has a very influential effect on both the environment and the economy together if it wasn't treated or being used. OMW contains a high rate of dangerous components that threaten human life. The most important of these are Phenol and Chemical Oxygen. OMW water becomes dangerous only if drained into the environment and interact with the heat and atmosphere. Environmentalists warn of the risk allowing owners of extraction factories of using OMW to irrigate trees because it may affect the groundwater. It also affects the environmental tourism and spreads bad smells. On the other side, OMW has many advantages if it is well treated. These include the manufacture of medicines and herbicides, Cosmetic industry, the manufacture of fertilizers and explained n this work, it can be used as cutting fluid. The OMW used in the experiments had been collected from one of the extraction mills after taking permission for that. After the tests, all waste of OMW together with chips were treated and safely disposed of.

2.3. Turning operation

A controlled turning experiment was conducted on 4-mm length sample cutting from 26-mm diameter rod of aluminum alloy to determine the relationship between the depth of cut, cutting speed and surface quality. The selected feed rate was held constant. The experiments were performed on a Benchtop Lathe — 160TCLi, powered with CNC machine at five levels of depth of cut and speed combinations as listed in Table 2. A Carbide pet cutting tool has been set up. This choice is because Aluminum has low hardness and good ductility, also this tool is relatively inexpensive. 3200 rev/min rotational speed with 0.5 mm depth of cut has been made for all samples to identify a specific reference to start with.

2.4. Milling operation

A controlled milling experiment was conducted on an aluminum block (with average face dimensions of 40 mm x 40 mm) to determine the relationship between the depth of cut and the surface quality. The selected feed rate was held constant. Numerous amounts of coolant were provided at the cutting zone throughout the experiment. The experiments were performed as conventional/ up milling at five levels of depth of cut and speed combinations as listed in Table 3. The tool was checked for wear after each run.

2.5. Surface Roughness Measurement

Surface roughness is a component of surface texture. Surface roughness (Ra) is the arithmetic average of the roughness profile. The surface roughness measurements of the workpiece were recorded using surfcom flex measuring machine for measuring surface roughness. No other formal cleaning process was used, and care was taken not to scratch the surface of the samples during handling.

Table 1. Experimental setup (Turning): Speeds and depth of cut (Constant Feed rate).

Runs	Depth of cut (mm)	Speed (rpm)	Colling oil
1-5	0.2	3200, 3000, 2800, 2600, 2400	OMW
6-10	0.4	3200, 3000, 2800, 2600, 2400	OMW
11-15	0.6	3200, 3000, 2800, 2600, 2400	OMW
16-20	0.8	3200, 3000, 2800, 2600, 2400	OMW
21-25	1.0	3200, 3000, 2800, 2600, 2400	OMW
26-30	0.6	3200, 3000, 2800, 2600, 2400	Standard

Table 2. Experimental setup (Milling): Speeds and depth of cut (Feed rate= 30 mm/min).

Runs	Depth of cut (mm)	Speed (rpm)	Cooling oil
1-5	0.2	1800, 2000, 2200, 2400, 2600	OMW
6-10	0.5	1800, 2000, 2200, 2400, 2600	OMW
11-15	0.7	1800, 2000, 2200, 2400, 2600	OMW
16-20	1.0	1800, 2000, 2200, 2400, 2600	OMW
21-25	1.2	1800, 2000, 2200, 2400, 2600	OMW
26-30	1.2	1800, 2000, 2200, 2400, 2600	Standard

3. Experimental results and discussions

The measured values of surface roughness are plotted against the five cutting speeds for each of the depth of cut increments as shown in Figures (1-4). Figure (1) shows the effect of the cutting speed on surface roughness. As common, increasing the cutting speed improved surface quality. The best result found to be when the depth of cut was in the mid-range (around 0.5 mm). Additionally, the average surface roughness values are re-plotted with respect to the cutting speed to examine the effects of depth of cut. The effect of depth of cut (as shown in Figure (2)) is less significant. As expected, the surface quality of the machined surface reduction with increasing the depth of cut (Figure 2).

The same observations of the turning operation (Figures 1 and 2) can be noted, also, for milling operation (Figure 3 and 4). In these figures, the effect of increasing the speed is clear on the surface enhancement. The results after a speed of 2200 rpm and depth of cut of 0.7 mm become better and more stable. Figures (5 and 6) show the same results in three-dimensional representations. These figures show that the effects of both parameters are not clear because of using a constant feed rate. The most effective parameter is the feed rate that aligns with the results of many references in the literature.

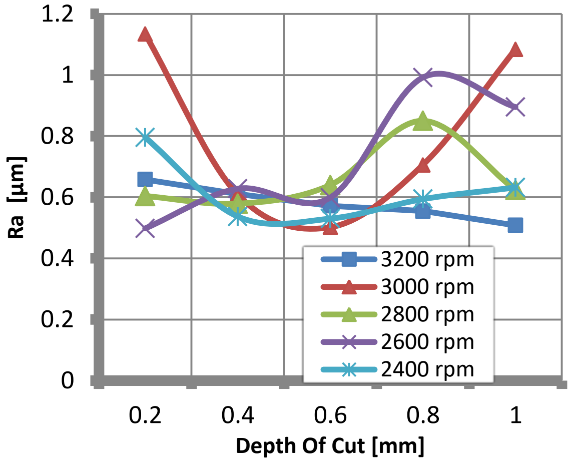

Figure 1. The plot of average surface roughness (μm) for the turning operations at different depth of cut (mm) and different speed. The feed rate is constant = 30 mm/min.

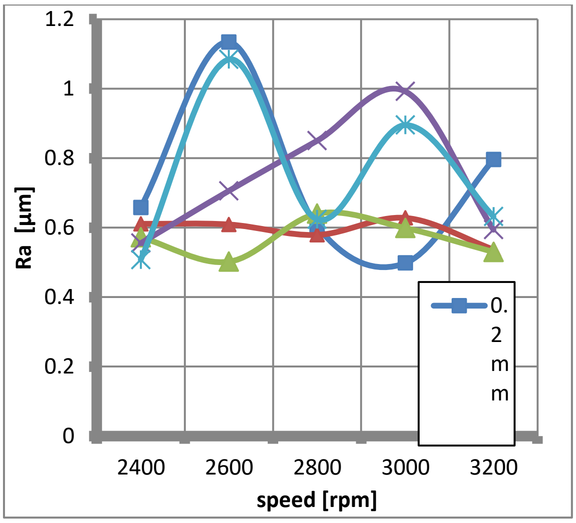

Figure 2. The plot of the average surface roughness (μm) for the turning operations at different speeds (rpm) and different depth of cut. The feed rate is constant.

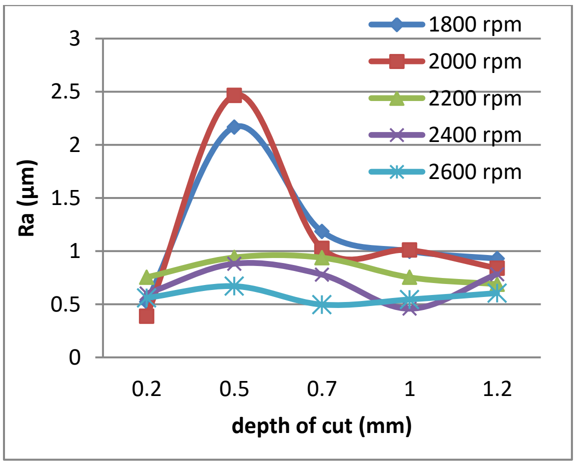

Figure 3. The plot of the average surface roughness (μm) for the milling operations at different depth of cut (mm). The feed rate is constant = 30 mm/min.

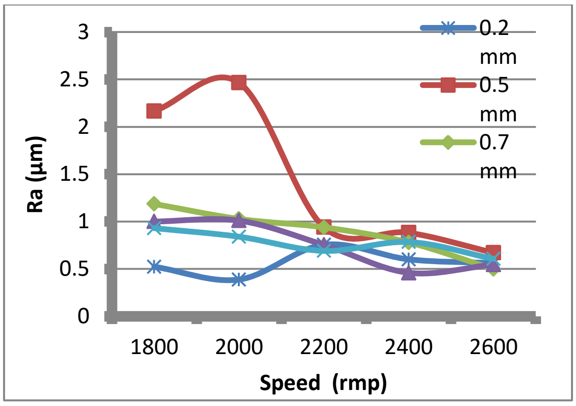

Figure 4. The plot of the average surface roughness (µm) for the milling operations at different speeds (rpm). The feed rate is constant.

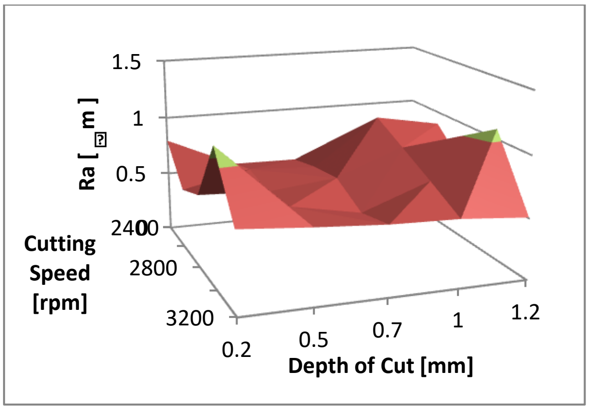

Figure4. 3D Graph for turning operation at a constant feed rate.

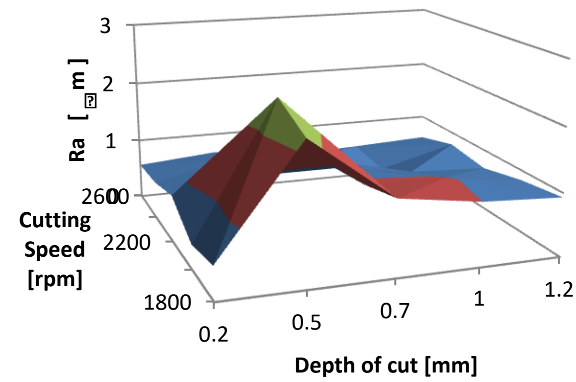

Figure 5. 3D Graph for milling operation at a constant feed rate.

Figures (7 and 8) show a comparison between the OMW as cutting fluid and standard sellable oil. The curves are close together with preference to OMW in the milling operation. Figure (8) shows a great effect on surface enhancement when using OMW especially at a speed of 2000 rpm.

Figure (9) compares the experimental results with two theoretical models based on the work of others [17 and 18]. The first model [17] which predicted the surface roughness with the effect of spindle speed, cutting feed rate and depth of cut. According to this model, the arithmetic average roughness (R_a) can be predicted by:

$$R_a = 3.179 + 9.826*F - 0.009*V - 0.922*D \quad (1)$$

Where R_a: surface roughness in µm, V: cutting speed in m/min, F: cutting feed in m/min and D: depth of cut in mm.

The Second Model [18] using the following formula:

$$R_a = 1.52 - 0.00189\ V + 0.000111\ N + 1.33\ F - 0.200\ D \quad (2)$$

Where R_a, V, F, and D are as before and N: spindle speed in rpm.

Figure (10) compares the milling results of this work with three mathematical models. The first model which includes the effect of spindle speed, cutting feed rate and depth of cut, and any two variable interactions, predicted the surface roughness [19]. Using these coefficients, the multiple regression equation could be expressed as:

$$R_a = 1.178854 - 0.000492\ N + 0.009897\ F - 0.17625\ D - 0.000003\ (N*F) + 0.000811\ (N*D) - 0.003012\ (F*D) \quad (3)$$

Where R_a, N, F, and D are as defined previously.

The second model was developed for dry and the third for Minimum Quantity Lubrication (MQL) machining using multiple regression analysis which can be applied to surface roughness prediction of end milling of aluminum under dry and MQL environments; analysis of variance (ANOVA) was used to determine the significance of cutting parameters on surface roughness [20]. The final prediction formulas for these models are

$$R_a = (12.68F^{0.69}D^{0.04})/N^{0.81} \quad (4)$$

$$R_a = (10.80F^{0.70}D^{0.04})/N^{0.82} \quad (5)$$

Where equation (4) is the mathematical model for dry condition and equation (5) is the mathematical model for MQL condition. The experimental results of this work, as shown in figures (9 and 10), are within the different models. This result proves that the use of OMW as a cutting fluid is an effective choice. The outlying points in the above figures can be qualified to factors such as the vibration of the machine, obliqueness in the workpiece, tool wear, the temperature of the workpiece, and variation in material composition.

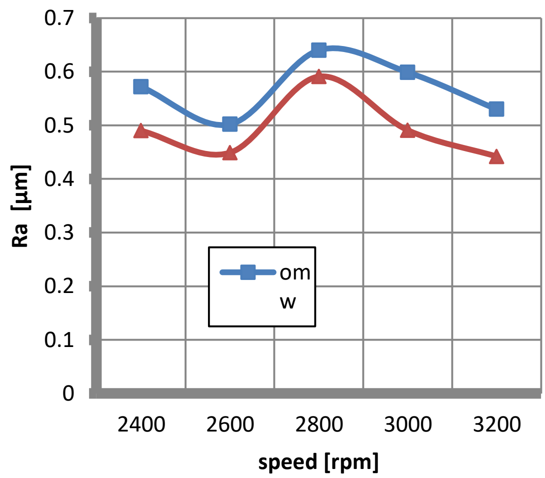

Figure 6. Plot of average surface roughness (µm) for the turning operations for different cooling fluid.

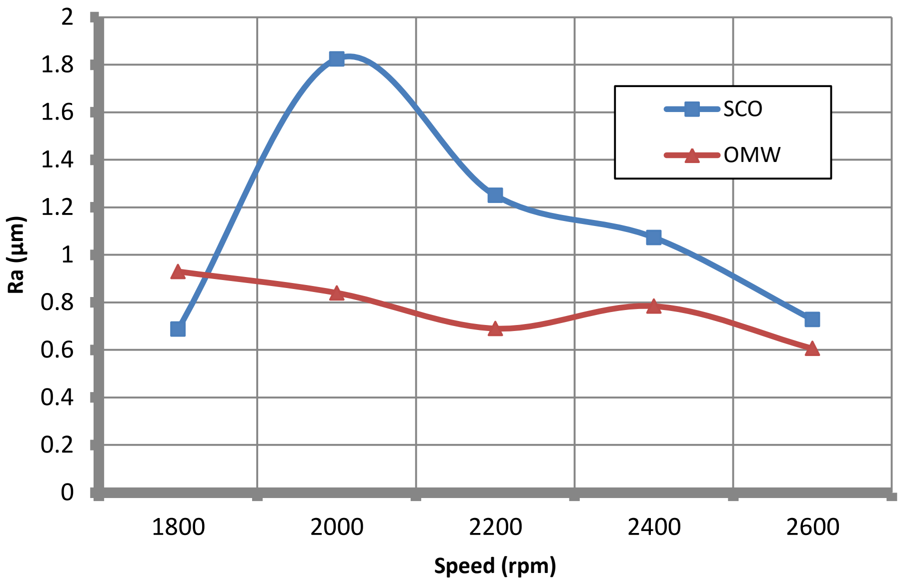

Figure 7. The plot of average surface roughness (µm) for the milling operations for different cooling fluid.

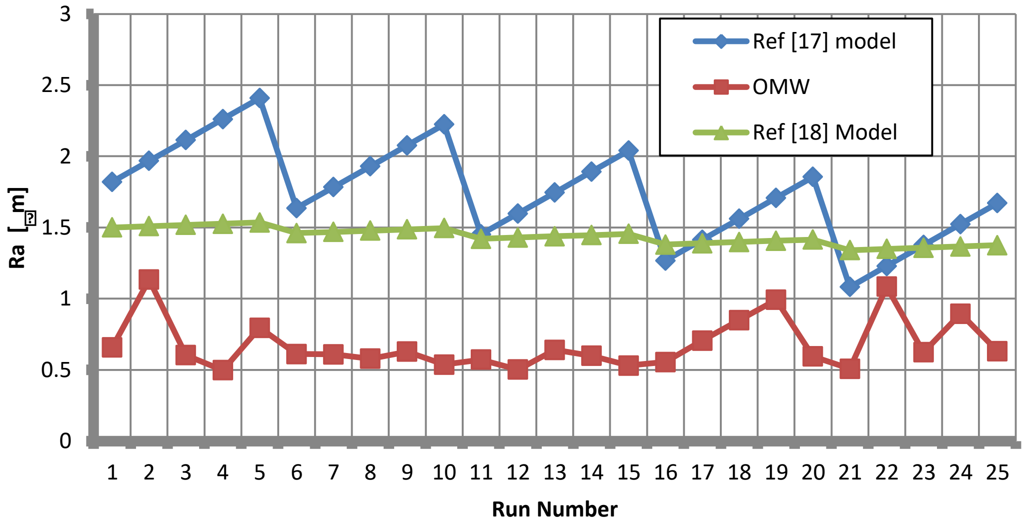

Figure 8. The plot of the average surface roughness (µm) for the turning operations for different methods.

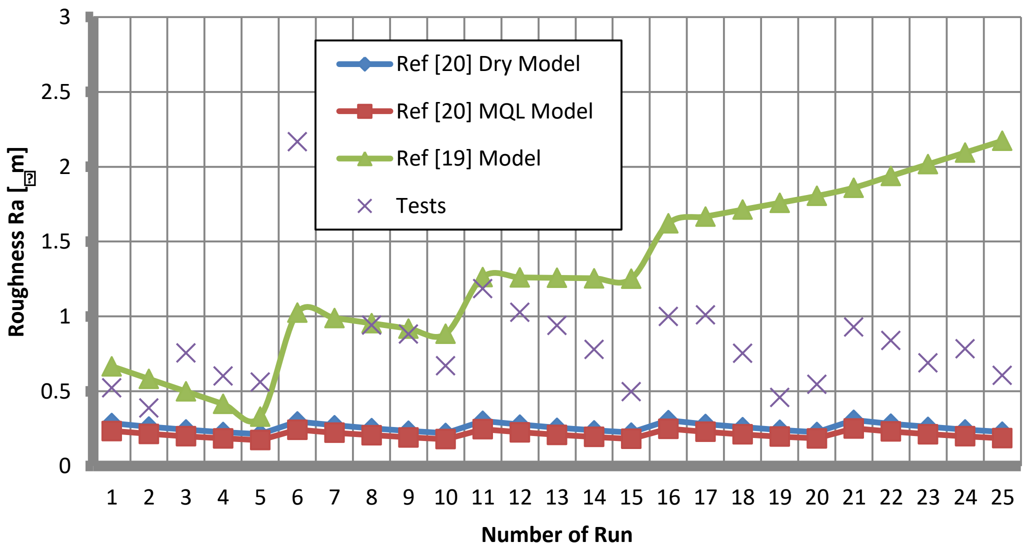

Figure 9. The plot of the average surface roughness (µm) for the milling operations for different prediction methods.

4. Conclusions

Jordan like other olive oil producing countries is facing severe environmental contamination problems due to the lack of full treatment of OMW at present. One possible use of OMW is to consume it in machining processes as a cutting fluid. Cutting fluid plays very important roles during the machining process. They are used to transfer heat, to lubricate the tool surface, and to transport the Chips. This article presents the roughness of the surface machined with the proposed cutting fluid, wherein the total number of measurements is equal to 60 trails. The results show that OMW worked effectively as a cutting fluid. Comparing with different theoretical and experimental models from literature, OMW worked very well. Detailed interpretation of the results is presented.

From this study, it may be concluded that the better surface finish may be achieved by turning and milling Aluminum alloy at low feed rate and high spindle speeds.

In conclusion, OMW can be used as a lubricant in turning and milling operations as an effective alternative to other conventional cutting fluids for environmental and health aspects. On further experiments, more investigations of the chemical hazard of this operation must be performed.

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