The Analysis of Experimental Process of Production, Stabilizing and Measurement of the Thermal Conductivity Coefficient of Water/Graphene Oxide as a Cooling Nanofluid in Machining

Ramin Ranjbarzadeh[1], Amir Homayoon Meghdadi[1*], Mohammad Hojaji[2]
[1]Young Researchers and Elite Club, Najafabad Branch, Islamic Azad University, Najafabad, Iran
[2]Department of Mechanical Engineering, Najafabad branch, Islamic Azad University, Isfahan, Iran
[*]Email of corresponding author: amir_meghdadi@pmc.iaun.ac.ir
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Abstract
The abrasion is a significant issue, especially in machining of rigid steels. A functional and suitable approach for enhancing the heat transfer from machining area is using an intermediate fluid with higher heat transfer potential instead of common fluids. The objective of this experimental study is to discuss production, stability and thermal conductivity examination of water/graphene oxide nanofluid considered as a new nanofluid used in machining process instead of common coolant. In this research, for thermal conductivity enhancement of a basic fluid (Deionized water), a nanofluid development method composed of two steps as well as particles of nano dimension consisting water/graphene oxide is used. Producing 16 different nanofluid samples, the sample having a higher stability than others is considered for examining the thermal conductivity. The Zeta potential measurement is used in order to precisely determine stability of the final sample of water/graphene oxide nanofluid. Considering the obtained results, a highly acceptable level of stability is concluded. In addition, the transient hot wire method as well as thermal analyzer system is used to measure the heat transfer coefficient of water/graphene oxide nanofluid. According to the obtained results, the thermal conductivity of water/graphene oxide nanofluid in most states has increased to 71% compared to the base fluid. It is also observed that water/graphene oxide nanofluid has a high heat transfer potential. Utilizing this nanofluid enhances the heat transfer, improves the surface quality and reduces the damages caused by machining instrument.

Keywords
Experimental Study, Machining Process, Nanofluid, Thermal Conductivity

1. Introduction

The development process of machining has always faced different challenges. Some of these challenges could be listed as machining of brittle pieces and rigid materials, attaining proper quality-oriented characteristics such as even surfaces or required dimensional and geometrical tolerances along with reduction of applied machining forces and increasing the overall lifetime of the tool.

Since tool abrasion impacts the efficiency of machining process, analyzing different parameters of machining including cutting speed and progress level in machining of rigid steels is of a high significance. Considering machining of rigid steels, for instance, the tool wearing is of a high rate, as a result the generated heat is high since the rigidity is high. A great portion of the generated heat during machining is transferred to the tool and hence the cutting tool is influenced by mechanical stress as well as major thermal stresses [1-2].

The cooling process of thermal devices is one of the most critical industrial requirements. However, the low thermal conductivity of coolants is the first limitation in expanding the range of their application in cooling processes. This fact should be considered that materials have distinctive mechanical, electrical, magnetic and thermal properties in nano dimension. These unique characteristics lead to introduction of a new concept called nanofluid which is a suspension of solid nanoparticles in a basic fluid. Small amount of a solid nanoparticle was added that is distributed in a fluid, yields in a significant enhancement of the thermal properties of that fluid.

Cooling is one of the significant challenges in machining process [3]. However, implementing fluids containing nanoparticles is a new approach for cooling machining tools. Enhancing the heat transfer of the used fluid for machining results in decreasing the adverse effects of generated heat during machining process [4]. The common cooling methods used in machining process include utilization of herbal oil and its combination with water, dry method, and least amount of lubricant method, cryogenic machining and nanofluids. In this study, the herbal oil is defined as a biodegradable coolant with high thermal stability which does not yield in oxidation [5]. There have been many different researches of both theoretical and experimental nature in terms of the thermal characteristics of fluids containing solid particles. They mostly confirm the fact that thermal conduction and convection coefficients significantly increase the heat transfer of nanofluids [6-8].

In recent years, extensive studies are done regarding properties of different nanofluids and their application in different studies. Verma et al. [9] tested the properties of nanofluid containing molybdenum disulfide nanoparticles while using three basic fluids including paraffin, triglycerides (canola oil) and lecythis in ball bearings. Considering the obtained results, the aforementioned nanofluid significantly reduces the friction coefficient and level of wearing.

Yu et al. also suggest that in a lubrication system, using a nanofluid containing copper nanoparticles as well as oil as the basic fluid reduces the friction and wearing of surfaces [10]. They also state that a thin protective film made up of copper with low elasticity module and low rigidity curve is formed on the surface which enhances its tribological performance.

Yu et al. [11] experimental study is on increasing the thermal conductivity of graphene nanofluid. In their tests, a 5% graphene nanoparticle in ethylene glycol as the basic fluid is used. The thermal conductivity coefficient of graphene nanofluid range varies between 4.9 to 6.9 W/m.k. In comparison with the basic fluid, the thermal conductivity coefficient of nanofluid is increased up to 86 %.

In 2012, Setti et al. used water/aluminum oxide nanofluid in their study called “Application of Nano Cutting Fluid under Minimum Quantity Lubrication to Improve Grinding of Ti 4v-6 Alloy”. In their experimental study, the applied forces for grinding and surficial leveling are measured for nanoparticles of different volume. The obtained results of their experimental studies for this particular alloy suggest improved surficial quality and reduced grinding forces [12].

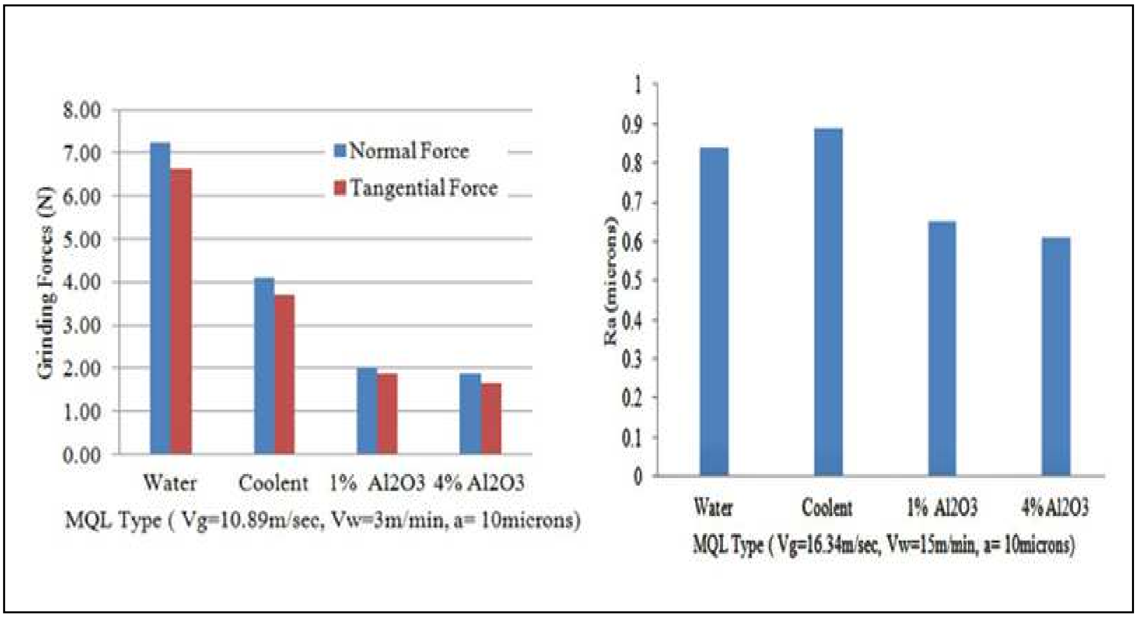

Figure1. Surficial flatness and grinding forces under the influence of different fluids [12]

Teng's et al. [13] experimental study examines the thermal conductivity coefficient of nanofluids. After conducting different tests, they suggest that reducing the nanoparticles size leads to an increase in thermal conductivity coefficient, and in a higher volume of fractions, the effect of temperature on thermal conductivity coefficient becomes significant. It is evident that the larger interface between solid material and fluid, the higher conductivity coefficient.

Considering the previous studies, it could be interpreted that implementing a nanofluid as cutting fluid in machining process leads to increase the heat transfer rate of machining tool. The objective of this experimental study is development, stability testing of water/graphene oxide nanofluid and in-vitro measuring the thermal conductivity coefficient of the intended nanofluid through transient hot wire method. Considering the high heat transfer potential of graphene oxide nanoparticles, it is predicted to witness a significant increase of thermal conductivity coefficient for the developed nanofluid. This property might significantly improve the machining process.

2. Machining and Abrasion of Tool

The phenomenon of tool wearing occurs when there is a contact between surface of a tool and swarf or their move along each other. This event is influenced by many factors. The tool wearing is among sensitive parameters of machining process. If it exceeds a certain limit, the tool wearing might directly affect some factors such as lifetime, overall cost of the tool, the quality of machined surface, dimensional precision of manufactured pieces and cutting power of the machine.

The use of cutting fluids in machining process leads to reduction of temperature and better lubrication. On the other hand, the use of machining liquids is an issue related to environment, health and production expenses. Considering the aforementioned problems, it is suggested to use the method of spraying the least amount of cutting fluid with flow rate of 10 to 100 ml per hour [14]. In another method, the use of cooling method and cool air flow is suggested as a mixed environmentally friendly method [15-16].

Najiha et al. examined the effects of using water/titanium oxide nanofluid for machining process of aluminum alloy. Their tests are conducted in different volume fractions of nanoparticles. The researchers reported the performance of nano-fluid as a cooling and lubricating fluid to be very desirable as the final outcome. Considering the results of conducted studies, it is noted that the use of nanofluid in machining results in cooling of tool and lubrication during the process [17]. In another study on thermally operated steel “AISI D2”, a water/ carbon nanotube nanofluid is used. The obtained results suggest the improved coarseness of tool surface and converting the surficial characteristics from nanoscale to nanoscale [18].

3. Experimental Approach

The use of nanoparticles in basic fluid to correct certain characteristics such as heat transfer and flow model leads to extensive recognition and application of these materials in different studies. After emergence of nano science and technology, the idea of using a suspension of solid nanoparticles in liquid for increasing thermal conductivity of fluids is raised. However, as the progress of nano technology continues, particles with size of less than 10nm could be synthesized. These particles generate relatively stable suspensions due to their small size.

The graphene oxide nanoparticles have certain characteristics such as high electric conductivity, a large specific surface, being hydrophilic, non-solubility and low density. In this study, the graphene oxide nanoparticles with 99% purity are used. The nanoparticles are made by US Research Nanomaterials. In order to ascertain of correct structuring of supplied nanoparticles, the samples are tested by scanning electron microscope and x-ray diffraction. The obtained results are represented in Figure 3.

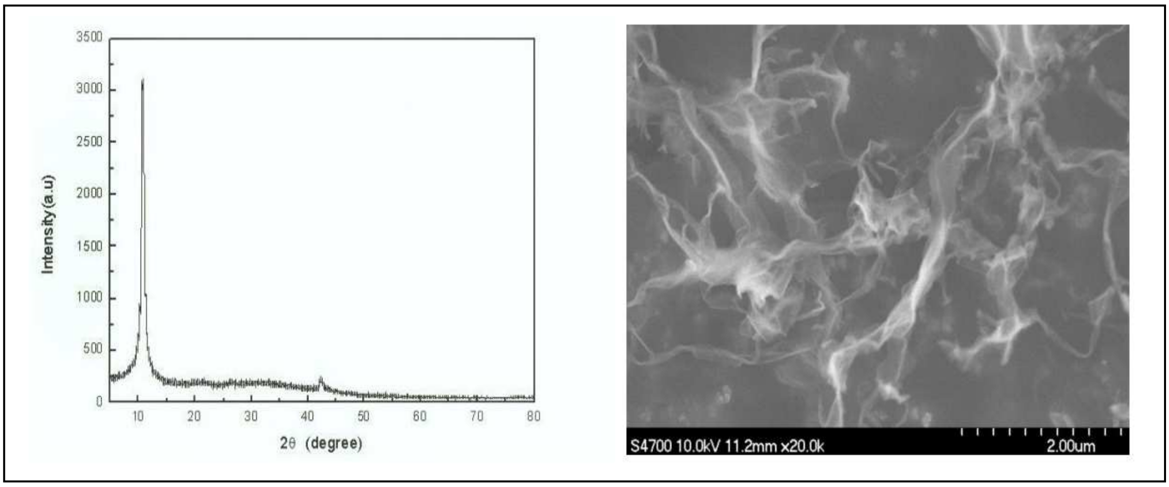

Figure2. SEM image and x-ray diffraction of graphene-oxide nanoparticles

3.1 Method of producing nanofluid

The graphene oxide nanoparticles are turned into nanofluid through three processes of chemical, magnetic and ultrasonic and adding the basic fluid (Deionized water). In the present study, the mass of nanoparticles is defined based on determining the volume fraction using equation (1). Considering the fact that nanofluid is developed through a two-step method, the weighting of required nanoparticles is done after preparing graphene oxide nanoparticles and using a digital scale with accuracy of 0.0001gr. By getting the basic fluid to the intended pH level and using magnetic mixer (Ret Basic Model), the combination of nanoparticles with basic fluid is considered to be done. In addition, the nanoparticles are uniformly distributed in basic fluid by using ultrasonic bath. The utilized ultrasonic bath is Parsonic 30S which generates 400W power and frequency of 28 kHz.

$$x = \frac{1}{1 + \frac{\rho_{bf}}{\rho_p}\left(\frac{1-\varphi}{\varphi}\right)} \tag{1}$$

The above relation serves the purpose of determining the volume fraction of nanoparticles. In this regard, φ is volume fraction of nanoparticles while ρ_{bf} and ρ_p refer to density of basic fluid and density of nanoparticles, respectively.

Figure3. Water/graphene oxide nanofluid, samples under stability test, 3 months after producing

3.2 Parameters of Research Variable

For suspension of nano-particles inside basic fluid through ultrasonic waves, the parameter of “waving duration” is highly influential upon stability of nanofluid. For each nanofluid, there is an optimal duration for waving of the system based on certain characteristics such as density of nanoparticles, density of basic fluid, size of clusters and interaction of fluid with nanoparticles. In this study for determining the optimal duration of using ultrasonic waves on the suspension, the four durations of 1, 2.5, 4.5 and 6.5 hours are set for each sample continuously. An ultrasonic bath system is used for this matter.

Acidity variation of basic fluid is another parameter which its variation is examined in this test. One can generate strong repulsive forces through increasing the surface charge density so as to stabilize the suspension. When the pH of solution gets away from isoelectric point (the isoelectric point refers to the concentration of potential controller of ions where Zeta potential is equal with zero), the surface charge density of particles and absolute value of Zeta potential increase. Consequently,

the colloidal particles attain higher stability which leads to increase thermal conductivity coefficient. In this test, the pH of basic fluid is examined in different levels namely 3, 6, 9 and 12.
Now, considering, the test variables, waving duration and pH of basic fluid in different samples, the stability variations are examined in the first step through photograph capturing technique. Then, the Zeta potential method is used to determine the stability level of seemingly stable samples.

3.3 Method of Examining Stability and Measuring Thermal Conductivity

In this experiment, a highly precise method (Zeta potential) is used to find the stability quality of a nanofluid. The test is conducted through DLS System (Model: Nano ZA Zen 3600). Based on a certain theory of stability, if the Zeta potential has a high absolute value, the electrostatic repulsion among particles increases which leads to proper stability of suspension. The particles of high surface charge are not inclined to form clusters. Usually, suspensions with high absolute value of Zeta potential are regarded as suitable suspensions from perspective of stability.
Due to the complicated mechanism and structure of nanofluids, it is impossible to use developed experimental models for relatively precise estimation of thermal conductivity coefficient. Therefore, in this study, the thermal conductivity coefficient of the nanofluid is experimentally studied. For measurement, the transient hot wire method which is one of the most precise approaches is used. After producing and stabilization of nanofluid, the thermal analyzer system is used to measure the thermal conductivity coefficient of the nanofluid in the temperature range of 20-50 Celsius. To conduct the test, the temperature bath (Model: WNB7) is used for fixing the temperature of sample during the test.

4. Results and Discussion

The preparation of nanofluid is done via adding nanoparticles to the basic fluid. This should not be confused with simple mixture of solid-liquid because preparation of nanofluid demands satisfaction of specific conditions. Some of these distinctive conditions include: uniformity, stability of suspension, attempt to inhibit formation of nanoparticle masses in nanofluid and lack of change in chemical nature of the fluid.
After the duration of applying waves, the nanoclusters are broken as much as possible and they form suspending particles so that it could be stated that after an optimal duration of applying waves, the resulting suspension arrives at the most stable state which is physically possible. However, in the most stable state, the surface of particles attains their maximum size while the ultrasonic waves break the clusters. Based on the test results, the optimal duration is 4.5 hours of continuous application of wave.
The optimal pH of basic fluid is determined based on stability results of four different samples. Considering the results of Zeta potential test, as shown in Figure 4, in pH 9 the absolute value for water/graphene oxide nanofluid is $\zeta = 41$. In this state, the nanofluid has an acceptable level of electrostatic repulsion when one considers the obtained result. This issue leads to confidence of invariance of properties of the nanofluid during the whole period from production to usage.

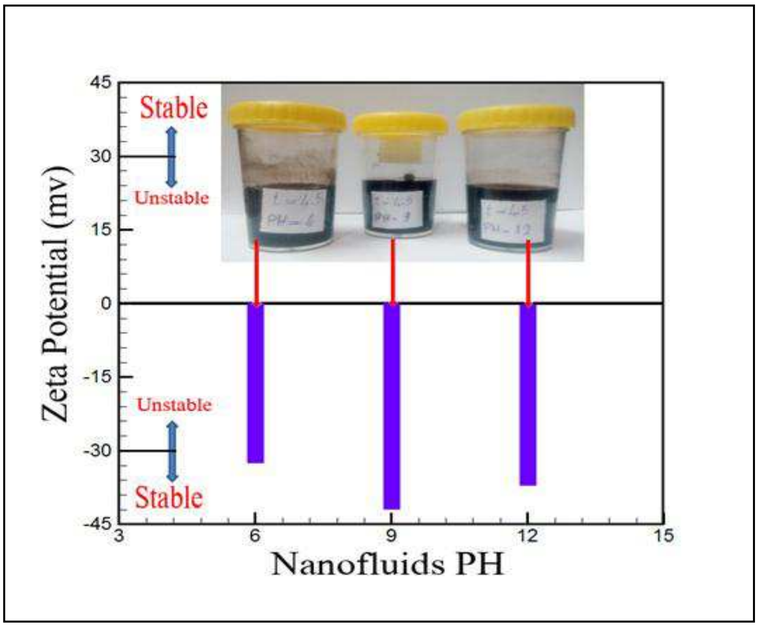

Figure4. Stability of nanofluid in different PHs based on Zeta potential

After determining the desirable pH value and optimal duration of applying waves, the water/graphene oxide nanofluid samples with different mass fractions of 0, 0.1, 0.2, 0.3 and 0.4 are produced and tested in the temperature range of 20-50 Celsius in order to precisely determine their thermal conductivity coefficient. The Figures 5 and 6 are presented for better understanding of variations of thermal conductivity coefficient through the two basic parameters of mass fraction and variance of nanofluid temperature.

In Figure 5, the results of increasing thermal conductivity coefficient of water/graphene oxide nanofluid as a result of increasing the mass fraction of nanofluid are observed. In low mass fractions, the difference of temperature has less influence upon thermal conductivity coefficient and the differences are insignificant. However, increasing the volume fraction is accompanied by attaining a higher thermal conductivity coefficient. In the case of highest volume fraction (i.e. 0.4%), the coefficient reaches its highest possible value in the conducted test. In this case, the proportion of nanoparticle to basic fluid is increased up to 71%.

Due to the fact that thermal conductivity coefficient of solid materials is higher than liquids, it is vivid that increased concentration of nanoparticles in the setting will add to thermal conductivity coefficient of nanofluid. In addition, the materials belonging to carbon group have naturally higher level of thermal conductivity coefficient.

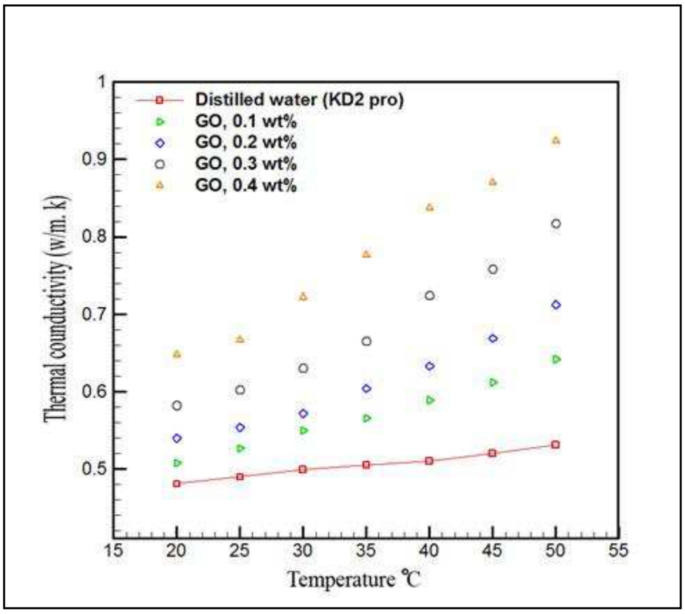

Figure5. Results of variation of thermal conductivity coefficient in relation to temperature in different mass fractions

Based on the represented results in Figure 5, it could be observed that by increasing the temperature in the range of 20-50 Celsius, the extent of increase in thermal conductivity for different mass fractions increases from 0.5 to 0.91 W/m. K. One of the significant reasons of positive results generated might be increased frequency of impact amongst fluid molecules and suspending particles as temperature rises. As the volume fraction of existing particles in the basic fluid rises along the temperature, the impact speed of molecules and Brownian motion also rises.

In Figure 6, the results of ratio of thermal conductivity coefficient of water/graphene oxide nanofluid compared to pure water as basic fluid are observed. Considering the increase of temperature during machining, in the test, the effects of temperature on thermal conductivity coefficient of water/graphene oxide nanofluid are studied. It is observed that the slope of incremental variations in relation to thermal conductivity coefficient of nanofluid in comparison to the basic fluid is generated which is specifically observed in higher temperatures. Amongst the major reasons of this increase, one could point to the increased random motions of particles and intermolecular forces of suspended nanoparticles in the basic fluid.

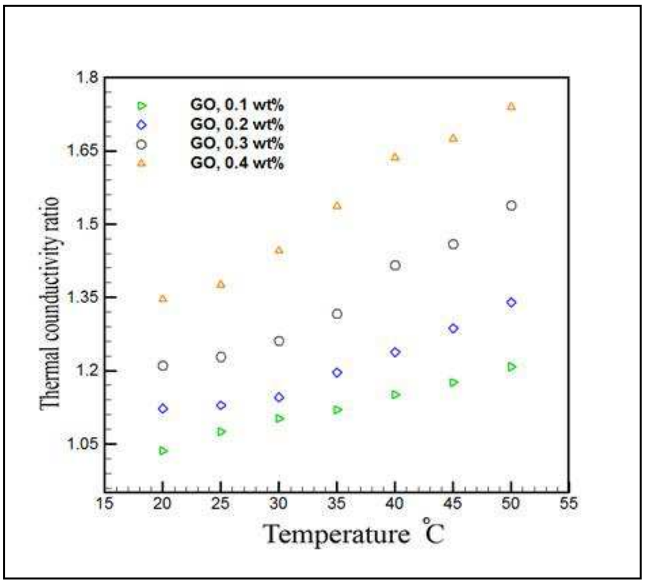

Figure6. Results of thermal conductivity coefficient of nanofluid compared with pure water in different mass fractions

5. Conclusion

In this experimental study, 16 different samples of water/graphene oxide nanofluid are produced. In regard to these samples, the acidity levels of fluids are 3, 6, 9 and 12 and ultrasonic waves are applied for 1, 2.5, 4.5 and 6.5 hours. The mass fraction of all samples is constant and equal with 0.1%. After conducting tests on stability, the optimal stable sample is determined based on development variables. Considering the availability of duration of applying ultrasonic waves and value of optimal pH for stable nanofluid, new samples with mass fractions of 0-0.4 are produced. Then, the measurement of thermal conductivity coefficient of nanofluid in temperature range of 20-50 Celsius is done, the results of which are detailed in the following:

1. Due to high thermal conductivity coefficient of nanoparticles existing in water/graphene oxide nanofluid, the nanofluid has a very high heat transfer potential compared to the basic fluid. This property makes it a suitable cutting fluid for transferring heat in machining processes.
2. The optimal duration of applying wave for attaining stability and uniformity of nanofluids is determined via a test with 4 states. Considering the conducted examination, the optimal state is using 4.5 hours of continuous application of ultrasonic wave.
3. Considering the absolute value of Zeta potential in nanofluid test, its stability in pH of 9 is highly favorable and it could also be used in the long-term. This might result from functional groups of graphene oxide nanoparticles, their nano dimensions and lack of difference in density compared with the basic fluid. This issue leads to stable characteristics of nanofluid.
4. The positive variation of thermal conductivity coefficient of water/graphene oxide nanofluid as a result of increasing the temperature from 20 to 50 Celsius represents 71% increase compared to the basic fluid. The aforementioned increase might cause the improvement of cooling process in machining. It might also inhibit wearing and other problems caused by thermal stress in machining tool.
5. As a result of increasing the mass fraction of nanofluid and considering the obtained results, it is observed that the value of thermal conductivity coefficient in nanofluid increases. This increase

is due to presence of more particles with higher thermal conductivity coefficient in comparison to the basic fluid.

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