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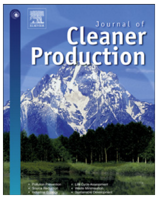

Fuzzy logic-based approach to investigate the novel uses of nano suspended lubrication in precise machining of aerospace AL tempered grade 6061

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ABSTRACT

Temper-grade aluminum alloy Al-6061-T6 is commonly used for many engineering purposes owing to its superior mechanical properties. Due to the practical importance, machining Al-6061-T6 alloy is crucial for different applications. The development of computer numerical control (CNC) of milling machines is in progress by researchers worldwide for its noteworthy advantages. The quality of machining determines the product's appearance, function and reliability. Appropriate lubrication at the machining zone improves the tribological characteristic of Al-6061-T6 alloy, leading to higher product quality. For reasons of ambiguity during machining, the soft computing technique is chosen to predict the output. In this particular research scope, a new fuzzy logic-based approach is adopted to determine the machining performance while milling Al-6061-T6 alloy using SiO_2 nanoparticles added to the lubricant. The effects of nanoparticle concentration, nozzle angle and air pressure are investigated to determine the optimum machining conditions, such as lowest cutting force, cutting temperature and surface roughness. Four membership functions are designated to connect with each input. The predicted results are computed by fuzzy logic and compared with the experimental results. The proposed fuzzy model exhibits high degree of reliability according to the experimental results. The computed results showed 96.195%, 98.27% and 91.37% accuracy with experimental results for cutting force, cutting temperature and surface roughness.

1. Introduction

Aluminum (Al) alloys are normally favored as one of the most appropriate and suitable metals for various applications. The characteristics of light weight, low cost and lucrative form are the main reasons aluminum and its alloys are so extensively used. Non-sparking and non-magnetic properties, electrical and thermal conductivity, reflectivity, and high chemical resistance are additional reasons for choosing aluminum and its alloys. Besides, ease of fabrication, non-toxicity, high strength and corrosion resistance make it popular in the construction, aircraft, marine and engineering industries.

Among all aluminum alloys, 6061 is the most commonly used due to its superior mechanical properties as well as excellent weldability. This precipitation hardened alloy contains magnesium (Mg) and silicon (Si) as major alloying elements. The mechanical properties of aluminum 6061 alloy depend on the extent of tempering (heat treatment). However, the Young's modulus of this alloy, which is approximately 69 GPa, does not depend on tempering. The elongation of this alloy is approximately 10% and the fatigue limit is 100 MPa under 5×10^8 reversed cycles. The thermal conductivity of Al-6061-T6 alloy is around 152 W/mK at 80 °C.

Aluminum alloys generally offer higher levels of machinability characteristics than other light weight metals such as titanium and magnesium alloys. However, a major problem encountered during dry machining at low cutting speed is built up edge (BUE). On the other hand, at high cutting speeds sticking is encountered. Thus, special tool geometries are required in both cases. Such machining difficulties are due to the presence of Mg and Si in Al-6061-T6 alloy.

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The presence of Si also contributes to the increment of tool rake angles and hence lower speed and feed are required. Greater machining cost is consequently a reflection of the above-mentioned issues.

In manufacturing sectors, several schemes are employed to reduce machining cost in an eco-friendly manner (Fratila, 2009). During machining, lubrication plays the most important role by having effects like prolonging tool life, improving surface finish, reducing cutting temperature and cutting force, and so on (Pusavec et al., 2010). Hence, it is important to employ a proper lubrication system as it covers 7–17% of the total manufacturing cost. Disposal and health hazards are other problems with commercial lubricants (Fratila, 2010).

To overcome such problems, dry and near dry machining (NDM) of AISI D2 steel using an environmentally friendly vegetable oil as lubricant and that is meant to completely eliminate mineral and petroleum-based harmful lubricants from the turning process, have been introduced (Sharma and Sidhu, 2014). Alternatively, researchers have developed mist lubrication, which is a mixture of air and cutting fluid supplied to the cutting zone at high pressure. Normally, an atomizer is used to atomize the cutting fluid in the presence of compressed air. The cutting fluid is then conveyed to the machining zone by low air pressure (Ueda et al., 2006). As the compressed air flows through the venturi path, a partial vacuum is created around the discharge nozzle. Mist lubrication thus reduces tool wear and improves tool life (Ueda et al., 2006). Besides, the novel biocide-free metalworking fluid (MWF) based on glycerol/water rather than conventional mineral oil-based MWFs for machining processes is a new solution to some environmental issues (Wichmann et al., 2013).

For further improvement, nanolubricants are recently being used for less oil consumption and higher performance. Moreover, nanolubricants are able to provide lubricity over a wide range of temperatures (Nakamura et al., 2000). Nanometer-sized metals, oxides, carbides, nitrides or nanotubes are dispersed in the cutting fluid for the preparation of nanolubricants. Typically, carbon nanotubes (CNTs), TiO_2, Al_2O_3, MoS_2, SiO_2 and diamond nanoparticles are used in lubricants. Often in literature and several publications the most similar areas available are discussed. For example, Cu nanoparticles were studied to understand how they work in lubricant oils to improve tribological properties and it was found that Cu nanoparticles with 130-nm mean diameter were more effective in reducing the coefficient of friction in all lubrication regimes (Zin et al., 2013). Besides, the implementation of nanolubricants (oils containing MoS_2) can also reportedly reduce the specific energy, friction coefficient, frictional losses and tool wear in the machining process (Kalita et al., 2012a,b). It has also been found that MoS_2 nanolubricants can effectively reduce sliding frictional losses by a continuous supply of active lubricant additives and by forming a stable, low-friction tribofilm at the sliding interface of the tool and workpiece surfaces (Kalita and Ajay, 2010). In addition, with MoS_2 nanolubricant in the machining process, performance in terms of force ratio and specific energy has shown substantial improvement compared with ordinary lubrication systems (Kalita et al., 2012a,b).

In the machining area where the tool works in very severe conditions subject to very high temperatures and pressure to shear the workpiece material, the tool wears rapidly as the friction coefficient between the tool and chip in the cutting zone is very high; in many cases tool fracturing occurs (Rahmati et al., 2014). To overcome such problems, lubrication is essential. But in severe conditions at the cutting zone where the temperature and pressure are very high, lubrication function is reduced, which is why using nanolubrication is unavoidable.

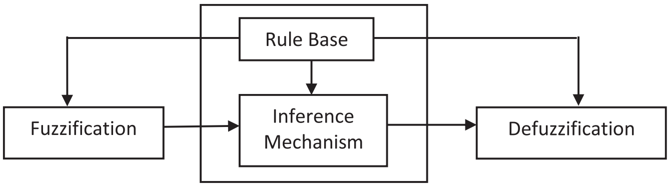

Fig. 1. The structure of a fuzzy system.

It is well documented that SiO_2 nanoparticles are most prominent compared with other nanoparticles thanks to their mechanical properties such as hardness and low cost. Moreover, reported results indicate that power and lubricant consumption is greatly reduced during the machining process in the presence of SiO_2 nanoparticles (Sarhan et al., 2011). In this research work, the performance of SiO_2 nanolubricant is investigated for precise machining of tempered-grade Al-6061-T6 alloy. Machining performance is measured as a function of nanolubricant concentration, nozzle angle and air pressure.

Handling nanoparticles without mixing them with oil is hazardous to human health because they would become airborne (Saidur et al., 2011). However, by mixing nanoparticles with lubricant oil, they are very unlikely to become airborne. Therefore, handling nanolubricant is safer compared with handling stand-alone solid lubricant (Yu and Xie., 2012). The complexity and uncertainty during machining processes are eliminated by applying fuzzy logic-based soft computing (SC) techniques (Shamshirband et al., 2010). The fuzzy logic-based model is significant in the matrix relationship containing input and output. For clarification, Fig. 1 presents the structure of a fuzzy system. Due to the nonlinear condition, fuzzy logic was selected to determine the performance based on input variables during the machining process (Sonar et al., 2006). Previous research also showed high accuracy of fuzzy logic analysis in estimating surface roughness during milling of brittle materials. In this work, fuzzy logic is applied to estimate the cutting force, cutting temperature and surface roughness values during Al-6061-T6 alloy milling using SiO_2 nanoparticles added as nanolubricant.

According to the results, the SiO_2 nanolubricant works well, especially in machining of hard materials. Ordinary lubricant oil cannot withstand high pressure and would become less effective. Therefore, when using nanolubricant, the oil acts as a carrier to introduce the nanoparticles into the cutting zone. As nanoparticles are solid, they can withstand very high pressure and temperature at the tool–workpiece interface. These act as billions of rolling elements to smoothen the machining process by reducing its coefficient of friction. Hence, surface quality improves and cutting force is reduced as well, leading to reduced power consumption and machining cost besides a more environmentally friendly process.

2. Design of experiments

Identifying the experimental array and selecting the lubrication parameters make the most important stage of this experimental

Table 1
The lubrication parameters and experimental condition levels.

Lubrication parameters		Level (*i*)			
		1	2	3	4
A	Nanoparticle concentration (wt %)	0	0.2	0.5	1.0
B	Air pressure (bar)	1	2	3	4
C	Nozzle orientation (degree°)	15	30	45	60

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