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ORIGINAL ARTICLE

# Cutting force reduction and surface quality improvement in machining of aerospace duralumin AL-2017-T4 using carbon onion nanolubrication system

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**Abstract** In machining of very high precision Duralumin AL-2017-T4 for aerospace applications, the shape varieties of the product lead to many different complicated shapes to be developed. The computer numerical control (CNC) milling machine facilities provides a wide variety of parameter set-up, making the machining process on the Duralumin AL-2017-T4 excellent in manufacturing complicated special products compared with other machining processes. However, the demand for high quality and fully automated production focuses attention on the cutting process, which are partial determinant of the quality of surface and affects the appearance, function, and reliability of the products. The key solution is to increase the effectiveness of existing lubrication systems in the machining process in order to improve product quality as it could reduce the friction component at the tool–chip interface. For further improvement, introducing the nanolubrication system could reduce the cutting force and produce much better surface quality as the rolling action of billions units of nanoparticles at the tool–chip interface could reduce the coefficient of friction significantly. In this study, carbon onion has been used as nanoparticle mixed with ordinary mineral oil at different concentrations to investigate the cutting force reduction and the surface quality improvement of CNC end-milling machined Duralumin AL-2017-T4. From the results, with using of carbon onion nanolubricant, the cutting force and surface roughness values are reduced by 21.99 and 46.32 %, respectively, compared with the case of using ordinary lubrication systems. This can be attributed to the tribological properties of carbon onion, which reduces the coefficient of friction at the tool–chip interface during the machining process.

**Keywords** End milling · Carbon onion nanolubrication · Cutting force · Surface quality · Duralumin AL-2017-T4

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## 1 Introduction

Aircraft engines, fuselage, automobile parts, and energy saving strategies in general promoted the interest and research in the field of lightweight materials, typically on alloys based on aluminum [1]. The aircraft airframe is the most demanding application for aluminum alloys to chronicle the development of the high strength alloys. Duralumin is the first high-strength, heat-treatable aluminum alloy, which was initially employed for the framework of rigid airships by Germany during World War I. Duralumin is an aluminum–copper–magnesium alloy which originates from Germany and developed in the USA as alloy AL-2017-T4. In manufacturing terms, the computer numerical control (CNC) milling machine can be used for machining AL-2017-T4 alloy as it can perform a vast number of operations, ranging from simple (e.g., drilling, slot, and keyway cutting) to complex (e.g., contouring and die-sinking) operations. Besides, the workpiece

and cutter movement can be precisely controlled to less than 0.025 mm. In addition, the capability of the CNC milling machine to make batch production would be a noteworthy advantage for machining [2, 3]. However, for more accurate and precise machining, the cutting force should be reduced as this force partially determines the surface quality and affects the appearance, function, and reliability of the products. The friction between the rake face of the tool and the freshly formed chip surface plays a vital role in influencing the ease of the metal cutting process and consequentially in reducing cutting forces [4]. The existence of clean surfaces and high hydrostatic stresses favors the formation of strong adhesive friction junctions and the extent of these can be limited by the provision of a suitable lubricant. The correct application of lubricants has been proven to greatly reduce friction, which in turn reduces the cutting force and improve the surface finish. Furthermore, a good surface finish, which is indicated by low surface roughness, not only assures quality, but also reduces manufacturing cost. Surface roughness is defined as a group of irregular waves in the surface, measured in micrometers. The roughness data obtained from measurements can be manipulated to determine the roughness parameter. There are many different roughness parameters, which include surface roughness ($R_a$), $R_z$, $R_q$, and $R_{sk}$. $R_a$ is universally recognized and the most used international parameter for roughness as it can be easily measured by graphical process. $R_a$ is selected as the surface roughness parameter in this study due to the fact that $R_a$ is the most widely used surface parameter in the industry. Low surface roughness is particularly important in terms of tolerances, as it reduces assembly time and avoids the need for secondary operations. This, in turn, reduces operation time and leads to overall cost reduction [5, 6]. Besides, lower surface roughness is also significant to improve the fatigue strength, corrosion resistance, and creep life of materials.

Although the significance of lubrication in machining is widely recognized, the usage of conventional flooding application in machining processes has become a huge liability. Not only does the Environmental Protection Agency regulates the disposal of such mixtures, but many countries and localities also have classified them as hazardous wastes. From an economic viewpoint, the costs associated with lubrication and cutting fluid is 17 % of the total production cost, which is generally higher than that of the cutting tool equipment, which incurs only 7.5 % of the total cost [7]. At present, many efforts are being undertaken to develop advanced machining processes which utilize a less amount of lubrication. Promising alternative to conventional flood coolant applications are the minimum quantity lubrication (known as MQL). According to Klocke and Eisennblatter (1997), MQL refers to the use of a minute amount of lubrication typically at a flow rate of 50–500 ml/h, which is approximately 3–4 orders of magnitude lower than the amount commonly used in flood cooling conditions [8]. In MQL, the lubricant is directly and in a precisely dosed manner applied at the cutting point and these will considerably improve the machining area and creates the possibility of using the cutting tool at much higher cutting speeds and feed rates. Therefore, it is possible to obtain not only an enormously increased productivity, but also a tool service longer life and better products' surface quality. The dry chips can then be recycled without incurring large cleaning expenses [9]. MQL has been reported to reduce friction, cutting temperature, and improve tool life due to its ability to penetrate into the chip–tool interface, which reduces cutting force and surface roughness [10–12].

In order to further improve the machining process, introducing the nanolubrication system could result in more reduction of the friction component as it is working as billions of rolling elements at the tool–chip interface and consequently produce much better surface quality [13]. Nanolubricant is a kind of new engineering material consisting of nanomaterial-size particles dispersed in a base fluid [14]. The requirements that have to be followed are, it must be able to sustain high machining temperatures present during the machining process and it must be non-toxic, easy to be applied, and effective in term of cost [15]. Several researchers investigated the role of fullerene nanolubrication in ball bearings and constitute into two group mechanism [16]. The first mechanism is direct effect of nanoparticles on lubrication enhancement which is rolling effect and protective effect, and it is found that the friction coefficient of the bearing immersed in the nanolubrication showed a significant decrease in friction coefficient. The second mechanism is the surface enhancement which proved from the specimen employed in the nanolubrication test was reused in new mineral oil test. It is found that the modified frictional surfaces from the former test did not change appreciably in the following frictional test, which indicates that surface modification results from nanoparticle abrasion is significantly enhances the lubrication properties.

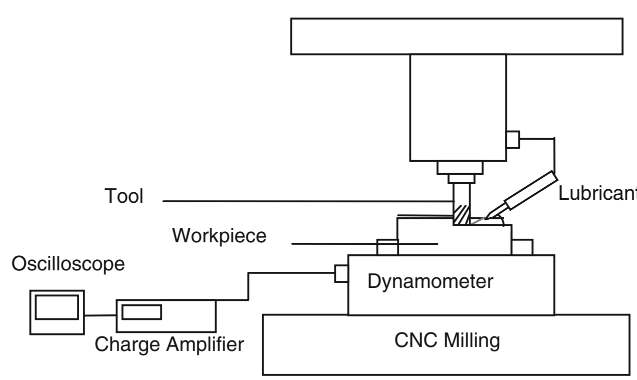


**Fig. 1** The experimental setup