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Influence of Copper Content on 6351 Aluminum Alloy Machinability

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Abstract

The main purpose of this work is to study the influence of copper content (Cu) in machining of 6351 aluminum alloy (Al-Si-Mg). The machinability was evaluated from measurements of drilling torque and drilling thrust force in cutting tool and surface roughness of the machined surface during drilling process. Samples of 6351 aluminum alloy were produced with different levels of copper (Cu) (0.07, 0.23, 0.94, 1.43 and 1.93%). Cutting speed and feed rate were varied in five levels (60 to 100 m/min and 0.1 to 0.3 mm/rev). The results showed that increasing the copper content in a Al-Si-Mg-Cu aluminum alloy increase the precipitation hardening through the stabilization of hardening phases like $Al_5Cu_2Mg_8Si_6$ and Al_2Cu, also the increase in amount of Al_2Cu. Thus, the samples of 6351 aluminum alloy with higher copper content, in general, showed higher hardness and ultimate tensile strength values, while the percentage elongation after fracture was lower. The drilling torque and drilling thrust force during drilling process increased almost linearly with feed rate increase. The samples with higher amount of copper (1.43% and 1.93%) led to higher drilling torque and drilling thrust force for feed rate over than 0.2 mm/rev. Although, the surface finishing of these samples machined holes was slightly worst.

Keywords: Copper Content, 6351 Aluminum Alloy, Machinability, Machining, Drilling,

1 Introduction

Aluminum is one of the metallic materials most used in metalworking industry and its use has greatly increased in the aeronautics and automotive areas. Low weight/strength ratio, good electric and thermal conductivity, mechanical strength and good machinability are some of the properties that improved their market share. The aluminum due to its excellent qualities has taken important place in engineering applications, making it the most produced non-ferrous metal in the metallurgical industry.

To attend the necessary requirements for engineering applications, aluminum is usually combined with other chemicals elements in the alloys form. Aluminum alloys 6XXX series contain silicon (Si)

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and magnesium (Mg) as major alloying elements, and they are present roughly in the proportion required for the formation of magnesium silicide (Mg_2Si), thus making that alloy heat treatable. Although not as resistant as the alloys of 2XXX and 7XXX series, 6XXX series alloys have good formability, weldability, machinability and corrosion resistance, with medium strength. Alloys in this group can be formed in the T4 temper (thermally treated by solution, but not by precipitation) and hardened after the forming to the properties of the T6 (thermally treated by solution and artificially aged) by the heat treatment of precipitation. The uses include architectural applications, bicycle frames, transport equipment, bridges rails and welded structures (ASM, 1992).

The 6351 aluminum alloy as well as 6082 and 6005A alloys contains a superior amount of Mg_2Si than 6063 and 6061 alloys with a substantial silicon excess. A 0.2% Si excess increases the strength of an alloy containing 0.8% of Mg_2Si in about 70 MPa (Tiryakioglu & Staley, 1996).

Beyond silicon and magnesium, other elements in smaller amounts, like iron, copper, manganese, chromium, zinc, titanium, are also added to Al-Si-Mg series aluminum alloys to give different properties. When copper (Cu) is added to Al-Si-Mg aluminum alloys, the Al-Cu-Mg-Si alloys family is formed with several properties and applications. The aging response of these alloys is often complex due the occurrence of many intermediate phases. Large strength increases can be achieved adding Cu in Al-Si-Mg alloys, in addition of substantial refinement of precipitate structure (Tiryakioglu & Staley, 1996). Increasing the copper content of 1 to 6%, the tensile strength increases from 152 to 402 MPa and the hardness increases from 45 to 118 HB (Zeren, Effect of Cooper and Silicon Content on Mechanical Properties in Al-Cu-Si-Mg, 2005). Man, Jing, & Jie (2007) found that the addition of 0.6% Cu to the 6082Al–Mg–Si alloy clearly increases the peak hardness and reduces the time to reach the peak hardness. The hardness value of the alloy with 0.6% Cu was always distinctly higher than that of the alloy without Cu during isothermal treatment at 250 °C. According to Jaafar et. al (2011) the addition of Cu (0.1 wt. %) results in refinement of needle-shaped precipitates and may also increase the density of precipitates amount. Also Kim et. al (2013), demonstrate that low Cu and Ag additions enhance the hardness and kinetically accelerate the formation of Mg_2Si precipitates, which is the main hardening phase in Al-Mg-Si alloys.

Due to the wide use of aluminum alloys, mainly in automotive and aeronautic industry, and their large participation in the market, the producers need more knowledge about the alloys behavior in manufacturing process to provide more technical data for his clients. In this scenario the machining is one of the most used processes in the industry.

The machinability can be evaluated by one or more criteria as tool life, metal removed rate, cutting forces, surface finish, chip shape, temperature, etc. (Trent & Wrigth, 2000). Compared to other materials, aluminum is easy to machine. However, considering the wide range of available alloys, it is necessary to go into detail about the characteristics of machining of aluminum alloys (Johne, 1994).

The machinability of 6351 (T6) alloy was investigated and the results showed that machining tools with PCD (polycrystalline diamond) compared with carbide tools, led to lower feed forces and cutting forces in addition to better surface finish (Reis & Abrão, 2004). Furthermore the amount of silicon in 6351 aluminum alloy has shown influence on cutting force. Smaller values of cutting force were obtained with 1.2% silicon content. The greater the amount of silicon in the aluminum alloy better is the surface finishing of the machined part (Da Cunha & Da Silva, 2012). Zedan & Alkahtani (2013) machining heat-treated (T6) Al–10.8Si cast alloys demonstrate that the increase in the levels of Cu and/or Mg in this alloy has a detrimental effect on drill life. Such an effect may be attributed to the formation of large amounts of the coarse blocklike Al_2Cu phase, together with the formation of thick plates of the Al–Si–Cu–Mg phase. Also the chip breakability of the alloys containing the Al_2Cu phase is superior to that of the alloys containing Mg_2Si. Thus, combined additions of Cu and Mg are expected to further refine the size of the chips produced. According to Elgallad et. al (2010) the addition of Sn or Bi to an Al-2.3Cu-1.2Si-0.4Mg alloy intended for automotive castings decreases its cutting force and moment significantly, which in turn improves the machinability of the alloy. Also the addition of Bi increases the fragility of the chip considerably whereas no distinct change in chip