Wear 362-363 (2016) 18–32

Contents lists available at ScienceDirect

Wear

journal homepage: www.elsevier.com/locate/wear

Cutting of aluminium alloy with abrasive water jet and cryogenic assisted abrasive water jet: A comparative study of the surface integrity approach

N. Yuvaraj*, M. Pradeep Kumar

Department of Mechanical Engineering, College of Engineering Guindy, Anna University, Chennai 25, Tamilnadu, India

ARTICLE INFO

Article history:
Received 12 February 2016
Received in revised form
7 May 2016
Accepted 9 May 2016
Available online 13 May 2016

Keywords:
AWJ
CAAWJ
Surface integrity
Impingement angle
Mesh size

ABSTRACT

Cryogenic assisted machining is a recent machining technique, which is used for producing definite components with a satisfactory surface condition. In the present work, surface integrity studies have been carried out on the abrasive water jet (AWJ), and cryogenic assisted abrasive water jet (CAAWJ) cutting of AA5083-H32 aluminium alloy by varying the jet impingement angles and abrasive mesh sizes. Micrographs, surface morphology, 3D surface topography, 2D roughness profile, XRD peak analysis, surface residual stress and micro-hardness have been characterized in the AWJ, and CAAWJ cut surfaces. Of the two cutting conditions, the CAAWJ cutting process enhances the functional performance of the cut surfaces, leaving no traces of severe wear tracks, while obtaining a uniform roughness profile pattern, higher surface compressive residual stress and hardening. The results indicate the effect of variations in the jet impingement angles, and the abrasive mesh sizes contributing a satisfactory surface condition, existing in CAAWJ by the Liquid Nitrogen jet.

1. Introduction

Surface integrity is one of the major selection criteria in any machined product, as it determines the type of manufacturing process that has been applied to the target material. It is defined as a modification of the material condition after the impact of the manufacturing processes. This alteration of the material includes the surface and subsurface alterations of the machined work material. Fig. 1 shows some of the possible surface and subsurface alterations grouped by a major mode of energy applied in the machining processes. These are drawn from Davim [1], who provides a comprehensive study of the surface integrity in the machining processes. Such alterations are produced by various forms of energy applied to the work material, such as mechanical, thermal, chemical and electrical energy. These cause alterations in the layer of the machined surface. Such altered layers have an adverse effect on the elements of surface integrity, namely, micro and macro cracks, microstructure alteration, hardness variation, residual stresses, heat affected zone, metallurgical transformations, recrystallization, and intergranular attacks. They also affect the functional performance of the machined products such as fatigue life, strength, corrosion resistance, etc.

The functional performance of the machined components can be improved by increasing the compressive residual stress and micro-hardness in the machined surface. These results are reported by M'Saoubi et al. [2], and, later, experimental and theoretical investigations by Jawahir et al. [3]. Such results have also been demonstrated by Pusaveca et al. [4], who noted increases in the hardness, compressive residual stress, and surface quality of the machined parts through the use of cryogenics in the machining of a nickel based alloy. Review studies on cryogenic machining-induced surface integrity have been reported by Kaynak et al. [5] later. Hence, surface integrity is the common selection criterion in the manufacturing processes.

Aluminium–Magnesium alloys (AA 5xxx series) are widely used in marine, automotive, and other structural applications. In general, the machining of these aluminium alloys by manufacturing processes is quite difficult compared to other alloys, as it is a work hardened alloy, offering poor machinability and surface integrity. Despite the machining done by conventional and unconventional machining processes, it leads to severe alterations in the machined surface layer. These alterations fall within the range of surface integrity, such as the heat affected zone, formation of residual stresses in the subsurface, dimensional inaccuracy, tool wear, poor surface finish, built-up edge formation, formation of cracks, and changes in strength and hardness as revealed by

* Corresponding author.
E-mail addresses: yuvaceg09@gmail.com (N. Yuvaraj), pradeep@annauniv.edu (M.P. Kumar).

http://dx.doi.org/10.1016/j.wear.2016.05.008
0043-1648/

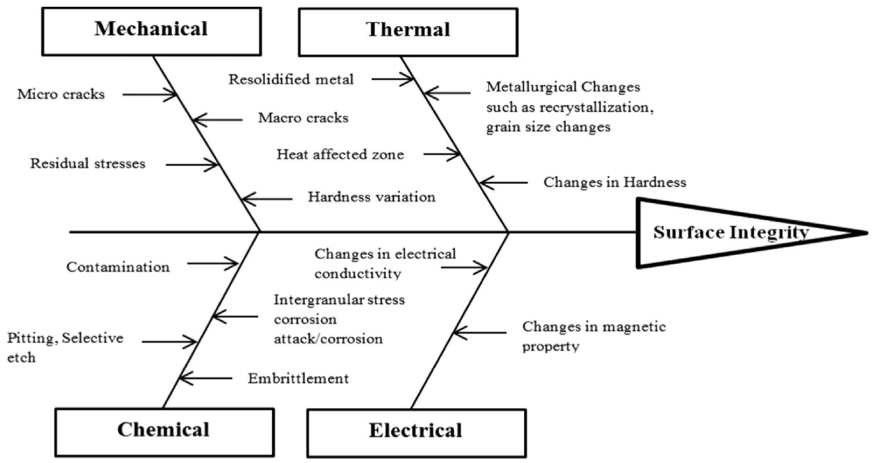

Fig. 1. Causes and effects of surface and subsurface alterations.

Totten and Mackenzie [6]. Researchers prefer the AWJ machining process, considering the superior quality of the machined surface obtained by this process compared to the other machining processes. Its advantages include the offer of a smaller heat affected zone, lower stress acting on the target material, no significant changes in the properties of the materials, etc. More detailed advantages of the AWJ machining centre have been mentioned by Folkes [7] who has made a comprehensive study of AWJ operations.

In AWJ cutting, the material is removed by the erosion process, wherein hard abrasive particles are suspended in a high velocity of the water jet stream, which, in turn, increases the acceleration of the abrasive particles, and their kinetic energy impingement towards the target material, causing material removal. This has been reviewed by Momber and Kovacevic [8]. The erosion process for ductile materials occurs through the cutting and deformation wear modes, as discussed by Hashish [9]. The cause and effect diagram shows that the energy sources, such as thermal and electrical, do not produce any adverse effect on the AWJ cutting process. The AWJ machined surface is usually altered through mechanical and chemical alterations on the target material. Alterations include the deformation effect, striation formation, abrasive contamination, intergranular attack, hardness variation, etc.

Some researchers have investigated surface integrity on the water jet, and AWJ machined materials. The details are briefly presented below. Boud et al. [10] have made studies on the surface integrity of AA 7075 aluminium alloy by the impact of the plain water jet cutting process. The results indicate improvement in the fatigue life of the aluminium alloy, caused by the generation of compressive residual stress induced by a plain water jet. Zhao and Guo [11] report, smooth AWJ cut surfaces being obtained on the hard materials, and the soft materials cut surfaces having severe wear tracks. Sadasivam et al. [12] introduced the abrasive water jet peening on the hard materials such as titanium and nickel. They found an increase in the compressive residual stress through an increase in the jet pressure, and the abrasive particle size. Kunaporn et al. [13] have studied the surface integrity of the AA6061-T6 aluminium alloy through the use of the various profiles of water jet formation, such as fuzzy jet, fan jet and round jet. They observed the production of a better surface integrity by a fuzzy jet, when a lower water jet pressure and a traverse rate are employed. Jegaraj and Babu [14] have studied the surface topography of machined AA6063 – T6 aluminium alloy by varying the ratio of the orifice to the focusing nozzle diameter in AWJ. The results indicate the effect of increasing the orifice and the focussing nozzle diameter does not degrade the quality of the cut surface that much. Akkurt et al. [15] have studied the various roughness parameters on different AWJ machined materials such as aluminium and AA6061 aluminium alloy, AISI 1030 and 304 steels, brass by a different traverse rate and thickness of the materials. Selvan et al. [16] have investigated the surface roughness of the AWJ machined aluminium by varying the level of the water jet pressure, abrasive mass flow rate, traverse rate and stand-off distance. They found the water jet pressure and abrasive mass flow rate directly proportional to the surface roughness.

Kovacevic [17] has studied the surface texture in the AWJ cutting of AISI 304 stainless steel by scanning electron microscope images. The results indicate the top cutting region being characterized by a smooth texture and the bottom cutting region by a rough texture, due to the formation of striations at the exit of the work material. Chen et al. [18] have investigated the causes of striation formation in the AWJ cut surfaces, and found the formation of striations arising out of the wavy distribution of abrasive particle energy and external effects. Hlavac et al. [19,20] have found that the tilting of the cutting head from the jet impingement angle of 90° improves the quality of the kerf wall cut surfaces through a reduction in the jet retardation. The formation of striation is found to be based on the target material type and the limit of the traverse rate used. Arola et al. [21] have studied the surface texture and residual stresses on the plain water jet, and the AWJ surface treatment on titanium. They observed the AWJ surface treatment inducing high compressive residual stress and also producing a rough surface over the plain water jet. The findings of the investigation done by Arola and Ramulu [22] indicate the influence of material properties on surface integrity as resulting from the AWJ cutting of different work materials, such as Al 7075-T6, Molybdenum, Ti-6Al-4V, Monel 400, and AISI 304 stainless steel. They found the occurrence of subsurface deformation on the AWJ cutting of metals. This happened due to the strain hardening of the metals, and the jet impingement angles. The investigation of previous researchers on surface integrity studies of the AWJ cutting metals has been limited to the surface topography of the AWJ cut surfaces and the compressive residual stress by the AWJ peening operations.

Recently, researchers have developed machining processes with the assistance of liquids at very low temperatures, such as cryogenics, for the improvement of process performance and surface integrity. Cryogenic machining processes increase machinability, by enhancing the material properties through the use of very low temperature cryogenic liquids. This is illustrated by Ravi and Kumar [23]. Among the low temperature cryogenic liquids, liquid nitrogen (LN_2) is environmentally safe for machining operations, as its disposal is easy with a small expansion ratio to