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The Impact of Plain Waterjet Machining on the Surface Integrity of Aluminium 7475

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Abstract

Embedding of grit during abrasive waterjet (AWJ) is known to have an adverse effect on component fatigue life. To address this issue Plain Waterjet (PWJ) Machining, which does not make use of any abrasive material may be used as an alternative process. This paper presents an analysis of the impact of PWJ Machining on the surface integrity of Aluminium 7475 parts. Plates of Aluminium 7475 are subjected to PWJ surface machining. A range of machining parameters is considered, including traverse speed, stand-off distance, jet pressure, and number of passes. These plates are then subject to surface analysis to measure surface texture and residual stress, prior to fatigue life testing. This analysis allows conclusions to be drawn with regard to optimal machining conditions for fatigue life improvement. It is shown that waterjet induces compressive residual stress that benefits fatigue life.

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1. Introduction

The technology of high pressure Waterjet machining is an extremely versatile process which has been significantly studied by a number of research teams [1, 2, 3, 4, 5]. It has found application in a wide range of industrial sectors, for processes such as cleaning, surface layer removal, cutting, surface machining, or other surface modification processes such as surface treatment or waterjet peening (WJP). As with all machining processes there are a wide range of significant parameters that must be optimised for a given application. For example different processing parameters and material properties have to be carefully assessed in order to produce the desired process qualities, such as material removal rate, and the resulting surface finish and integrity [6, 7, 8]. Surface integrity is becoming increasingly important for Waterjet machining as it finds applications in challenging industrial sectors such as the aerospace industry. The most common form of waterjet machining is Abrasive Waterjet machining, in which additional abrasive particles are added to the jet to enhance material removal rates. This increases the efficiency of the process significantly, however in many applications the residual abrasive particles that become embedded in the machined surface are a source of concern. These particles have been shown to reduce fatigue life [9, 10, 11], and in addition lead to other problems with subsequent processes such as welding, or surface deposition. To address this work has focused on the use of Plain Waterjet (using no abrasives) machining as an alternative process [12].

In this paper the effect of the plain waterjet machining process on the life span of components is assessed. While previous studies have focused on the optimisation of surface finish, or material removal rate, in this work the full surface integrity of processed material is assessed. This includes an analysis of both

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surface finish, as well as surface residual stress.

Residual stress as a result of Waterjet treatment of surfaces has been exploited in the development of WJP which is a relatively new application of the waterjet technology [13]. It is a mechanical surface strengthening process where high-frequent impact of water drops on the surface of metal components, which causes local plastic deformation. As a result, high compressive residual stresses are induced in the surface-near layer, which leads to enhanced surface hardness and fatigue life of components [6]. With the development of ultra-high pressure pump technology, surface treatment using PWJ can compete with other techniques in many applications for a wide range of applications, including cleaning, coating removal, roughening to enhance bonding characteristics, or peening to improve the fatigue properties [10, 11, 14, 15]. There are also many advantages are offered by the WJP process especially in leaving a clean surface, with the absence of thermal effects [6, 15]. As ultra-high-pressure waterjets can cause surface erosion or surface damage, this must be taken into account when applying WJP. Chillman et al. state it is important to determine the optimum conditions to promote a controlled surface preparation without inducing detrimental material erosion for this reason [14]. In the case of Waterjet Machining, material erosion is implicit leading to a complex surface state. Surface roughness is often increased, while at the same time some level of residual stress is generated in the surface. While a good understanding of surface roughness can be obtained using a wide range of measurement techniques, it is conversely much harder to measure the residual surface stress. As such once material removal has been initiated there is no clear understanding of the level of residual stress that has been developed. In addition there is currently not a clear understanding of how the process impacts on residual stress, for example, if there are optimum process parameters that lead to enhanced levels of residual stress.

An understanding of both surface roughness, and surface stress is critical for assessing the surface integrity of machining components and ensure optimal part lifetimes. For example fatigue is an important concern in the design of engineering components, with fatigue failures generally originating at the surface of components. These may be due to service induced flaws, environmental factors, and particularly the surface integrity resulting from manufacturing processes are all sources for premature failure [16]. Fatigue damage on the surface of a component typically develops due to the surface integrity resulting from manufacturing, such as the residual stress and the presence of stress concentrations originating from the surface topography. In general, the fatigue strength of engineering components increases with a decrease in the surface roughness [17], and an increase in residual compressive stress [6, 18].

The paper presents the findings of an initial investigation into how surface integrity as a result of Plain Waterjet machining impacts on component fatigue life. Aluminium is used for testing as it is widely used for flight-critical airframe structural components, and aluminium alloys are the overwhelming choice for the fuselage, wing, and supporting structures [19]. Aluminum 7475 offers strength and fracture toughness while resisting fatigue crack propagation [20, 21]. A set of parameters which could provide acceptable surface finish and removal rates are determined and used to produce fatigue test specimens. These specimens are milled by waterjet using a fanjet nozzle designed for wide area surface removal [22], with a range of different parameters selected to in order to see the effect of Plain Waterjet on fatigue life. Measurements of surface roughness and surface stress were collected using white light surface profiling, and x-ray diffraction respectively. These results are then used to determine the overall surface integrity and its' impact on fatigue life.

2. Experimental Procedure

The high-pressure waterjet system used in this investigation employed a 5-axis Water Jet System (Ormond) with KMT Streamline SL-V 100S Plus ultra-high pressure intensifier pump capable of providing maximum pressure of 413.7MPa (60,000 psi). A fanjet nozzle was used as shown in figure 1. This nozzle is very effective as the jet covers a wide area and therefore removes a large area from the material.

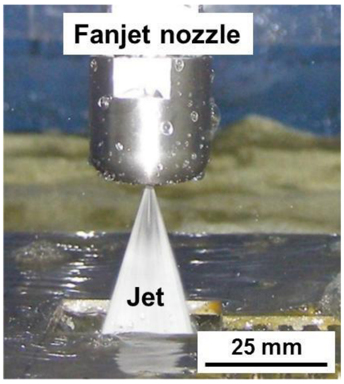

Fig. 1. Shows the fanjet nozzle, with the associated jet shape

The fatigue tests were carried out using an Instron 8801 Servohydraulic test machine with capacity of ±100KN load cell with Hydraulic wedge grips frequency sign wave. For both the machined and