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A study on the compressive residual stress due to waterjet cavitation peening

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ABSTRACT

The repetitive cyclic loads on the forming tool tend to fatigue failure. Molybdenum-based high-speed steel forming tool is extensively used for producing bevel gears but, often failure occurs at the root of tooth zone. To increase the tool life, an attempt has been made to provoke beneficial compressive residual stress on the root surface of form tool by waterjet turning cavitation peening process.The cavitation peening operation is done in the forming tool by directing the high-pressure waterjet of 27 MPa to the root section of the teeth region. The cavitation operation is governed by the system parameters like waterjet pressure at the nozzle exit, stand-off Distance, nozzle angle and the processing time per unit length. The residual stress induced on the sample is confirmed through X-ray diffraction technique and the effects of beneficial residual stress are measured at different operating conditions on hardness and surface profile and they are compared with the nascent sample. The study reveals that lower operating levels of Stand-off distance, nozzle angle of 45° induce more compressive residual stress around tooth region with less distortion at the surface profile. The waterjet impinged surface is observed through microscopy examinations and evaluated.

1. Introduction

The applications of waterjets are in the range from cleaning to cutting in different fields like construction, maintenance, and manufacturing industries. Among the different applications of waterjets, water jet peening is a novel surface treatment process that has gained momentum in the recent past, due to certain unique characteristics. Soyama et al. [1] investigated the influence of jet pressure and the nozzle geometry of the cavitation peening and reported that the water hammering effect due the impingement of water particle was found to be responsible for the surface erosion. Sadasivam et al. [2] delivered that with the force-controlled treatment, it became inevitable to induce compressive residual stresses inside the top surface layers with negligible deformation in surface topography. Ijiri et al. [3] have made an attempt to increase the cavitation rate through the induced supplementary nozzle and it yields a delay in erosion rate particularly at the center part of the workpiece.Soyama. [4] revealed that the cavitation jet air peening improves the fatigue strength more than the cavitation Water Jet Peening (WJP) and the observations confirm the improvement in fatigue strength over the non-peened samples.

Azhari et al. [5] conducted WJP studies on Al-5005 and delivered that the influences of machining parameters like water pressure, feed rate, number of passes and low standoff distance significantly determine the surface roughness and hardness of the material.

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Nomenclature

M2HSS	Molybdenum based High-Speed Steel
AWJM	Abrasive Waterjet Machine
WJM	Water Jet Machine
WJP	Water Jet Peening
SOD	Stand-Off Distance
Ra	Surface roughness
XRD	X-ray Diffraction
LVM	low carbon vacuum melt
AA	High strength Aluminium Alloy
Sq	Root Mean Square roughness
Ssk	Skewness
Sku	Kurtosis
Sp	Maximum peak height
Sv	Maximum valley depth
Sz	Maximum height of surface
Sa	Average roughness

Srivastava et al. [6] have measured the influence of pulsed waterjet on stainless steel and found that the low jet pressure of about 20Mpa is sufficient to induce hardness and also for conversion of tensile stress to compressive stress.Zhanshu et al. [7] investigated the effects of waterjet peening parameter on Al 6061 alloy and identified that water jet hammering pressure alone has a significant impact in inducing residual stress. Soyama [8] was found that there is an increment of 51% fatigue life on duralumin plates that have fastener holes where the hole region has undergone WJP operation. Boud, et al. [9] have studied the effect of process parameters on the surface integrity of the AA7075 material and have stated that the fatigue life greatly depends on the surface roughness and the residual stress.

Chen et al. [10] through the experimental works have confirmed that WJP on titanium alloy, spring steel, and Inconel induces compressive residual stress on the top surface by 45–60%, increase stored energy by 20–200% and has no influence on the surface roughness. Han, et al. [11] stated that the fatigue strength could be increased with the prevention of crack growth initiation in the surface of the material and it could be achieved by inducing the compressive residual stress to the depth of 140 μm. Azhari, et al. [12] studied the effects of WJP parameters on the surface characteristics of carbon steel 1045 and found the change in hardness value up to the depth of 200 μm. Beyond this range, the hardness values are almost similar to the base material.

Dong et al. [13] have studied the effect of WJP in SCR420H carbon steel combined with heat treatment process and confirmed that the compressive stresses of the material inside the surface layer have uniform dispersion within the structure. Further, this action improves the life of the gears. Sadasivam et al. [14] have investigated the residual stress of titanium alloy treated with AWJP and found that the load control pre-stress improves 50% surface residual stress and 10% improvement is found in the maximum residual stress. Hashimoto et, al. [15] investigated the stability of the compressive residual stress caused by the WJP in the welded nickel alloy in the pressurized water and identified that the stress relaxation would occur, due to the regaining of the severe plastic deformation. Guian et al. [16] had studied on the crack driving forces that are produced due to the welding/cladding residual and concluded that the cracks may tend to propagate from the outer surface for cladding residual stress.

Bozic et al. [17] commented that the residual stress is an important factor while in determining the fatigue crack growth rate. According to Maximov et al. [18] fatigue strength to structure, irrespective of compressive residual stress, there are some other governing factors are also has a significant effect likely; smooth surface profile, the microstructure of the surface. Lieblich, et al. [19] made a comparative study of the fatigue behavior of biomedical titanium alloy treated with WJP and grit blasting. It was found that the fatigue resistance of shot blasting with alumina particles was more and improved 15% hardness than the water jet peening. Azhari, et al. [20] have analyzed the effects of WJP on fatigue performance and reported that the residual stress induced into the surface is limited to 100 μm. They have also stated that the treated samples have a lower fatigue limit. Azhari, et al. [21] have also investigated the influence of water jet peening on the surface finish and the change of hardness on austenitic stainless steel 304 with multiple passes of the waterjet. It is stated that maximum hardness and less roughness can be achieved only on the combined effect of surface hardening and the multiple process steps of water jet treatment. Naito et al. [22] proposed a technique using recirculate shots accelerated with high-pressure water jet on the surface of the stainless steel and found that compressive residual was introduced up to 600 μm depth. This will increase the fatigue strength by 25% compared to the unpeened surface.

According to Xie and Rittel [23], Pure waterjet machining is found to be compromising technique to import residual stress on the surface of the sample with least surface distortion. Abhishek et al. [24] performed surface modification treatment for thermal relaxation on Inconel 718 by using laser shock peening, cavitation peening, and ultrasonic nanocrystalline surface modification technique and results confirm that the most thermal relaxation factor is removed by the cold working process. Farayibi, et al. [25] introduced a new surface modification technique as plain water jet peening tailed by pulsed electron beam irradiation for the laser clad surface of titanium alloy. The least surface distortion is produced on plain water jet milling and it tends to get increases with the increase of a number of passes. Barriuso, et al. [26] compared the WJP of AISI 316 LVM material and the titanium alloy. The results showed that the WJP could increase the surface hardness to 300 HV from 210 HV and the hardness beneath the surface also increased up to 100 μm. Ijiri et al. [27] evaluated the microstructure and the hardness on Cr-Mo steel machined by waterjet peening had concluded that due to cementite protrusions in pearlite grains tends to form voids in the area of 0.5–1.0 mm whereas there is no such signs are found beneath the surface.

Inducing compressive residual stresses into the surface layer will enhance the fatigue strength characteristics of the material. The objective of this work is to provoke beneficial compressive stress to a hardened M2HSS tool by means of abrasive waterjet cavitation peening. This forming tool is used to produce bevel gears. Repetitive cyclic load results in fatigue failure and the analysis proven that fatigue cracks are initiated at the root of tooth zone. The crack tends to propagate and ultimately tool failure after some cyclic application of load. To increase the tool life, waterjet cavitation peening operation is performed at the root section of the teeth. The resulting residual stress is evaluated by X-ray Diffraction (XRD). Analysis of the induced section shows an affordable compressive

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