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Towards Optimization of Vibratory Manufacturing Process in Aerospace Industry

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Shot Peening is a relatively common technology to improve the fatigue life of aerospace parts. However, the high surface roughness post shot peening, results in a debit on its aerodynamic efficiency. Hence it is common practice to apply an additional vibratory manufacturing process like vibropolishing onto the aerospace part thereby bringing the surface roughness to drawing requirements. In this paper the author has investigated an optimization of vibratory manufacturing process where the high cost shot peening process could be eliminated. The author also introduces a process monitoring and control method for the optimized process with a demonstration of repeatability and reproducibility at a micron level into the material thickness. Finally, through a fundamental approach the author also opens the possibility of further improving the efficiency through optimization of the process.

NOMENCLATURE

HCF= High Cycle Fatigue
RPM= Rotations Per Minute
RS= Residual Stress
IN= Inconel

1. Introduction

Improving High Cycle Fatigue (HCF) and aerodynamic efficiency are the two main objectives of surface conditioning of aerospace parts within Rolls-Royce. For a Trent XWB blisk airfoil for example, Shot Peening (SP) is usually used for improving HCF and vibropolishing is used to achieve a desired aerodynamic efficiency.

Fig. 1 Shot Peening set up of a blisk drum [1]

Vibratory peening is a relatively novel technology that could combine the benefits of both SP and vibropolishing thereby having significant potential in reducing the manufacturing cost of a blisk drum. This method also opens the potential of having a relatively greener and leaner manufacturing value stream. However, one of the biggest challenges in terms of industrialization of vibratory peening is the absence of an established mechanism of process control. SP uses Almen strip [2] peening and a visual coverage assessment as process control. While coverage may not be relevant to vibratory peening due to a shiny surface post VP, a process control for residual stress must be established to enable industrialization. Ciampini et al has demonstrated that Almen could be used for vibropolishing setup [3]. Some more studies are also emerging in terms of using Almen system for vibratory peening[4–7], but lacks visibility in terms of repeatability. Another challenge associated with vibratory peening is the comparison of residual stress compared to SP. Recent studies using Walther Trowal machine for blisk drums has shown that compared to shot peening the residual stress imparted is low due to the low energy nature of the vibratory peening process[8]. Hence in this paper an effort is made to address the above two gaps by demonstrating repeatability of Vibropeening process in a production environment and a fundamental approach to improve the energy of vibratory peening process.

2. Methodology

A vibratory peening machine from Walther Trowal namely TFM 58/32 is used for study[8]. At each RPM and amplitude, experimental trials were completed and Almen deflections were documented. A saturation curve was obtained, using saturation curve solver from Electronics Inc, USA from various Almen heights at different timing which was used to calculate the Almen intensity. Once desired Almen intensity is obtained, trials have been repeated by two different operators to study capability and repeatability using Minitab. Residual stress was measured at the center of an IN718 workpiece (proprietary heat treatment) using an XSTRESS Robotic X-Ray Diffraction (XRD) measurement system from Stresstech Oy, Finland, with layer removal, using electropolishing. A BS EN 15305:2008 test standard was used for XRD measurements.

3. Results and discussions

3.1. Process optimization for desired requirement

Previous experiments with the trough on blisk airfoils have resulted in compressive residual stress which is usually lower than shot peening. An experimental approach was adapted to improve the fixture stiffness with a hypothesis of higher stiffness resulting in higher impacts at a given time with higher peak force. The hypothesis was based on a relative approximation of the experimental setup to a cantilever in vibration [9].

$$f = 1/2\pi \sqrt{(k/m)}$$

A stiffer hollow fixture was designed, and trials were carried out. It was found out that the improvement if fixture stiffness resulted in an increase of Almen intensity by around 300%.

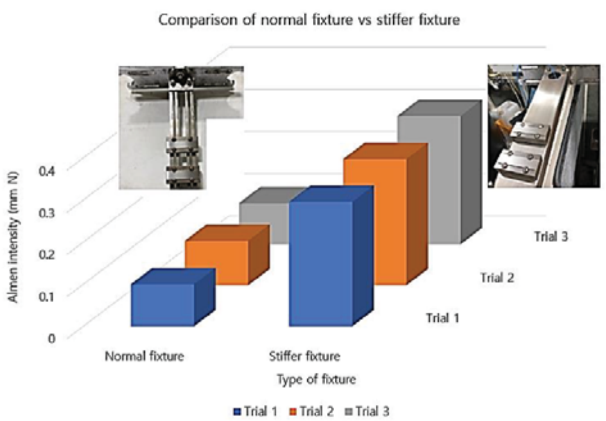

Fig. 2 Almen intensity for different fixtures

3.2. Process capability

Almen intensity was found to be consistent for the 30 experimental trials with minimal variation. A process failure mode effective analysis was completed to document a control plan of the process to enable the consistency of the process. The I-chart and the moving range chart indicates process is stable. Capability histogram is centered well within Upper Spec (0.35) and Lower Spec (0.25). Normal Prob Plot has a normal distribution curve with P value = 0.148. Cpk which is the measure of process capability in short term period is found to be 2.15 and Ppk which is the measurement of process capability for a long-term period is found to be 2.43 both of which is higher than 2 indicating potential capability of the process for industrialization.

Based on the intensity trials, Residual stresses on a specific IN718 coupons are found as below. The results seem to have reasonable overlaps with larger variability towards the surface. This may be due to the larger uncertainties in the calculation of residual stress and the minor variations in microstructures from material to material[8].

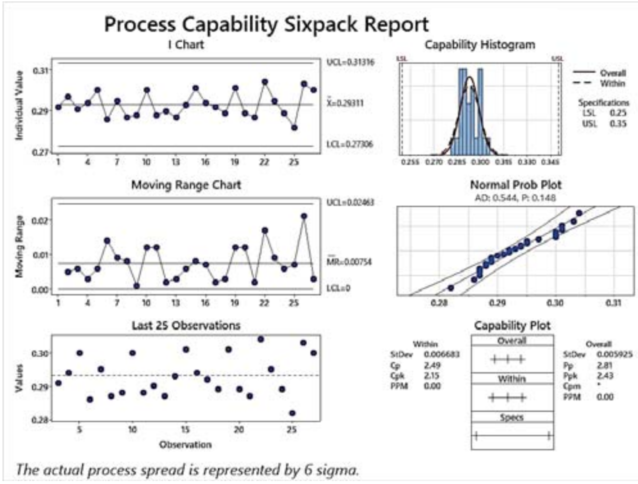

Fig. 3 Capability sixpack report for vibratory peening

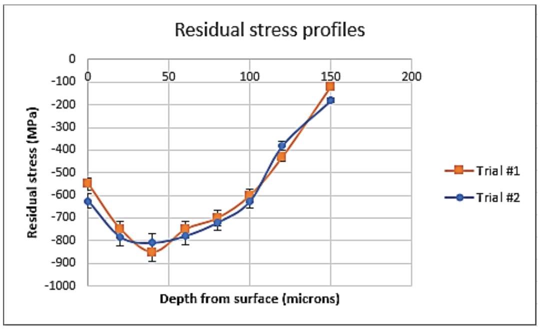

Fig. 4 Repeatability of residual stress

3. Conclusions and future work

In this research the authors have demonstrated the capability of vibratory peening to be an industrial solution with good Cpk and Ppk values. The residual stress at micron levels within the material are also repeatable within measurement uncertainties. The authors also demonstrate the potential for improving the process even further through an optimization of fixture. More work could be done through a topology optimization project for a best possible vibration signature for the fixture for best intensity. Also work could be done in terms of establishing repeatability from a residual stress point of view by having a detailed look into microstructures and performing more repeats. Currently the results are restricted to two repeats due to non-availability of coupons of specific material conditions. Furthermore, studies can be done to corelate the results to residual stress and fatigue on actual aerospace components.

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