THE USE OF CONTROLLED SHOT PEENING TO IMPROVE THE FRETTING FATIGUE BEHAVIOUR OF FLAT ON FLAT ALUMINIUM CONTACT

C. A. Rodopoulos[1], M. W. Brown[2], Sp. Pantelakis, S. Gardiner[4] and R. Edwards[2]

[1]Materials and Engineering Research Institute, Sheffield Hallam University, City Campus, Howard Street, Sheffield S1 1WB, United Kingdom.
[2]Department of Mechanical Engineering, The University of Sheffield, Mappin Street, Sheffield, S1 1JD, United Kingdom.
[3]Department of Mechanical Engineering and Aeronautics, University of Patras, Patras, GR 26500, Greece.
[4]Airbus UK, New Filton House, Bristol BS99 7AR, United Kingdom.

ABSTRACT

Flat on Flat contact best replicates conditions of fretting fatigue in aircraft single or double lap joints. Fretting fatigue is characterised by a number of complex mechanisms including stick to slip transition and mixed mode crack propagation which diverts after a specific depth, defined by the contact pressure or bolt pressure, to a mode I crack propagation. Extensive experimental characterisation utilising, apart from traditional S-N curves, fractography and laser 3-D profilometry, found that the typical U shape fatigue life (at constant axial varying normal stress) primarily depends on the stick to slip transition. The above, amplified the criticality of the surface roughness and near surface residual stresses, which when compressive can increase the surface wear resistance. To address the issue, surface engineering treatment in the form of controlled shot peening (CSP) was utilised. After achieving the required level of residual stress, the surface was subjected to super-finishing conditions to deliver uniformity of the surface roughness. The experimental result indicate that CSP has the potential of increasing the fatigue life of lap joints as much as 300% and thus reducing the time-dependent statistical distribution of multiple site damage.

INTRODUCTION

The fretting fatigue (FF) of bolted joints, riveted joints and other structural members subject to cyclic loading, is a serious issue in ageing airframes and has been the focus of much research [1-5]. Depending on parameters such as the clamping force and the mechanical properties of the material(s) in contact, the fatigue process in high load transfer joints can dramatically change in terms of the location and the type of fatigue cracks. In high load transfer joints where the clamping forces are generally high, FF cracks are dominant. Additionally, interference fitting of the fasteners creates tensile remaining stresses in the areas where fretting cracks are expected to initiate. A viable solution to the problem can be the application of controlled shot peening (CSP) [6]. CSP has a significant effect on the mitigation of fretting wear and FF. The resultant improvement in the FF life of a specimen has been documented to be over 22% [7] and even up to the order of 50% [8]. The phenomenon known as FF can modify the structure of a surface, by means of: plastic deformation, attendant work hardening, the generation of heat, the possible over aging of age-hardened materials and the formation of metastable phases such as “white layers”[9]. FF leads to surface and near surface degradation that causes the premature initiation and propagation of fatigue cracks [10]. In general FF is a combination of two dynamic phenomena: wear and fatigue [11]. Wear influences FF in a number of ways. The most important, is the alteration it produces in the contact stresses [12]. The fretting action of two surfaces results in the production of a fretting scar. When the relative displacement of the surfaces in contact (slip) is small, fretting scars tend to be patchy with little fretting wear. At higher values of slip range, considerable wear is encountered over the whole contact area [13]. Although surface damage produced by a fretting action can take the form of fretting wear, the more damaging aspect of fretting is FF, where the fatigue strength of the material is also seriously degraded [14]. Under a gross slip regime, fretting wear is the prevalent damage mechanism, whereas under a mixed stick-slip regime, FF is the dominant factor [15]. De los Rios, et al [16], have found that the mechanisms of crack initiation and failure are different between peened and unpeened conditions in FF. The initiation of fatigue cracks requires the attainment of a critical magnitude of local cyclic plasticity at the crack initiation site, a process that is more difficult at a shot peened surface due to the compressive residual stresses and work hardening of the peened layer [16]. Having a compressive surface residual stress results in less wear than having a tensile stress [17]. Bignonnet [7], has observed that shot peening shifts the crack initiation point from the surface to an internal defect, thus improving the fatigue strength at the surface. de los Rios, et al [16] have stated that in unpeened specimens the initiation of FF cracks is always in the form of three-dimensional semi-elliptical surface cracks. However, in peened specimens cracks have been reported to initiate both at the surface and at the subsurface of a component [16]. The feature of CSP that is most likely to prevent the propagation of cracks, is the presence of compressive residual stresses that can reduce the magnitude of the far field stress [7] [8]. In work carried out on austenitic stainless steel, Waterhouse et al [8] showed that CSP restores the fretting-fatigue strength at 10^7 cycles to the value of the normal fatigue strength without fretting. It was thus concluded that shot peening does not prevent the initiation of cracks by the fretting action, but markedly inhibits their propagation. In this work, experimental results obtained from the use of CSP are presented. The CSP parameters were selected in order to delay the stick to slip transition and thus to hold-up the maximisation of shear stress.

EXPERIMENTAL RESULTS

Fatigue testing was performed on a BI-AX 200 Mayes equipped with four servo-controlled hydraulic actuators. A single servo valve controls each pair of actuators, so that symmetrical loading may be applied. In addition, each axis is provided with a separate hydraulic power supply, load cell, displacement monitor and digital control unit, such that independent management of the axes can be achieved, under either modes of load or displacement control. A schematic illustration is depicted in Figure 1. The geometry of the specimen is depicted in figure 2a. Enlarged cross sections at either end of the specimens mean that the nominal axial stresses experienced in these regions are approximately 47 % of those in the centre section. This reduction in stress is sufficient to ensure that fatigue failures do not occur in the grips. The specimens were machined along the rolling direction. The normal load was applied to the specimens by means of two symmetrically placed bridge pads as shown in figure 2b. Strain gauges were bonded to the upper and lower surface of the bridges, in between the bridge feet, the signals from which were used to measure the friction forces, with each bridge being independently calibrated to ensure a good degree of accuracy. Cyclic loading was introduced in terms of a fully reverse loading, R=-1, and a sinusoidal waveform. The testing frequency was set at 20Hz while along the testing period laboratory temperature was monitored between 17.2 and 24 ^{o}C.

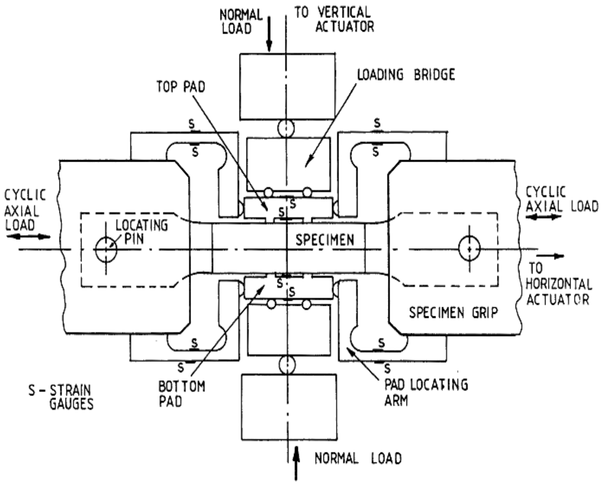
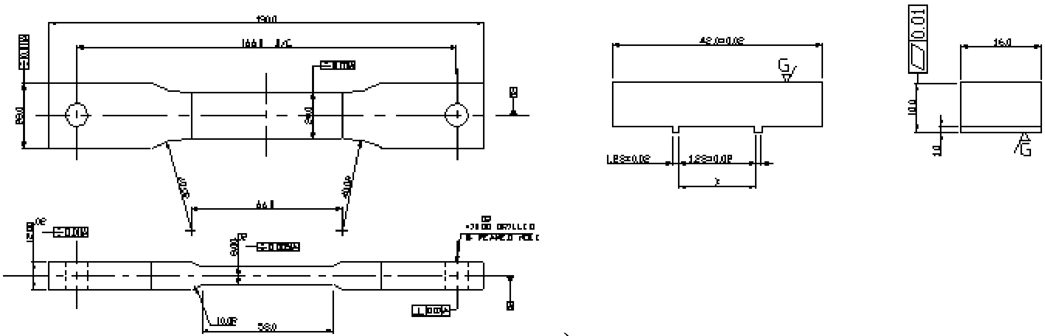


Figure.1: Testing setup.



b)

a)

Figure.2: a) Testing specimen and b) bridge pads. All dimensions in mm.

The material investigated was aluminium alloy 2024-T351, the material is used by Airbus for the construction of the lower skin of an aircraft wing. The chemical properties of the alloy are located in table 1a the mechanical properties in table 1b.

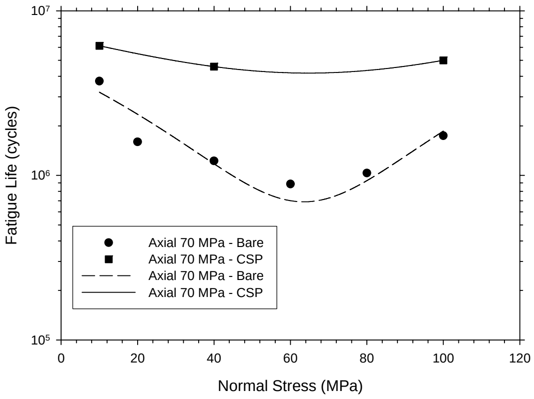
Table 1a: In house EDX analysis of the chemical composition of aluminium alloy 2024-T351.

Si (%)	Fe (%)	Cu (%)	Mn (%)	Mg (%)	Cr (%)	Zn (%)	Ti (%)	Unspecified		Al (min)
								(each)	(total)	
0.5	0.5	3.8 - 4.9	0.3 - 0.9	1.2 - 1.8	0.1	0.25	0.15	0.05	0.15	rem

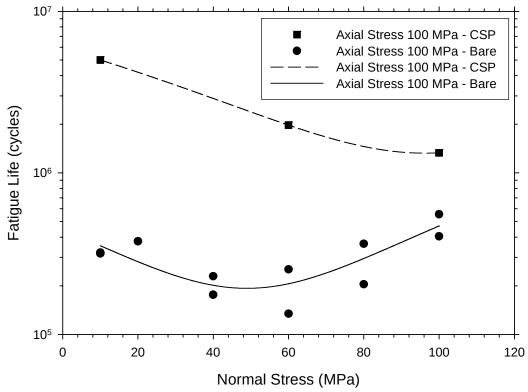
Table 1b: The mechanical properties of aluminium alloy 2024-T351.

Tensile strength (MPa)	Yield strength (MPa)	Elongation (%)	Hardness (HB)	Shear strength (MPa)	Fatigue strength (MPa)
470	325	20	120	285	140

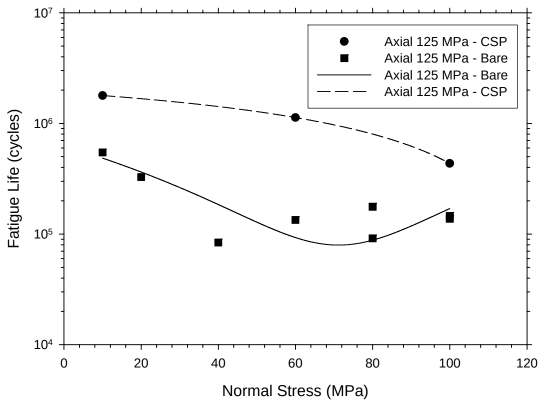
Controlled shot peening was performed by Metal Improvement Company in Derby UK using super-finishing conditions. CSP is a cold-working process where mainly spherical particles impinge the surface at predetermined kinetic energy levels. During impact, the surface yields but being restrained by the substrate results into the development of a compressive residual stress profile. The profile is known to be the product of a) the plastic stretching of the surface due to multiple shot indentation and b) a subsurface stress linked to the Hertzian pressure created by forces normal to the surface due to shot impingement. CSP is known to a) induce unstable residual stresses (residual stresses tend to relax to saturation with the introduction of stress); b) induce near-surface strain hardening characteristics; c) increase the roughness of the surface and d) induce refining of the near surface grain structure. To avoid localised slip conditions or premature stick/slip mixture by broken asperities on the surface, Super-finishing was selected as final machining procedure. Super-finishing uses oxalic acids and vibrofinishing stones to preferentially remove surface asperities. The oxalic acid oxidises the surface which causes loss of cohesiveness of the asperities and increase susceptibility to micro honing and thus removal of the most positive surface areas (peaks). Vibrofinishing stones are selected to cut the positive surface areas (positive valleys) while leaving the negative valleys untouched. The technique is ideal for contact conditions where weak peaks are susceptible to debonding [18]. Figure 3 compares the fatigue life of bare and peened specimens for different values of axial and normal stress.



(a)



(b)



(c)

Figure.3: Fatigue life behaviour of bare and peened specimens subjected to axial stresses of a) 70 MPa; b) 100 MPa and c) 125 MPa for a variety of normal stress levels.

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