Materials Science & Engineering A 607 (2014) 341–350

Contents lists available at ScienceDirect

Materials Science & Engineering A

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

Mechanical and metallurgical characterisation of electroformed nickel for helicopter erosion shield applications

D.P. Davies *, S.L. Jenkins [1]

Materials Technology Laboratory, Box 103, AgustaWestland Limited, Yeovil, Somerset BA20 2YB, United Kingdom

ARTICLE INFO

Article history:
Received 21 October 2013
Received in revised form
25 March 2014
Accepted 26 March 2014
Available online 4 April 2014

Keywords:
Electron microscopy
Mechanical characterisation
Non-ferrous alloys
Fatigue

ABSTRACT

The influence heat treatment has on the tensile, notch toughness, microstructure and fatigue properties of electroformed nickel have been studied. From the test data it is clear that by exposing electroformed nickel to temperatures in excess of 250 °C a significant loss of tensile strength, ductility and notch toughness occurs. In addition stiffness has been shown to gradually increase when exposed to temperatures from 200 °C onwards. The change in properties appears to be associated with microstructural changes, i.e. the crystallite structure is thermally unstable and gradually recrystallizes leading to breakdown of the fine crystallites and subsequent grain growth. In the case of ductility the severe reduction is considered to be primarily due to embrittlement caused by sulphur within the electroform precipitating out around the grain and sub-grain boundaries. Consequently, for electroformed nickel to be considered an engineering material for erosion shield applications it should not be subjected to temperatures above 200 °C.

Based on erosion shield cut ups, electroformed nickel appears to be essentially isotropic in nature due in part to the extremely fine crystalline microstructure. As mechanical property variability is greater with electroformed nickel when compared to wrought products it is essential that integral mechanical property test pieces are employed in order to be able to fully characterise the properties within the electroform. Certain electroforming defects have been shown to lower high cycle fatigue life; hence it is vitally important that in case of critical components, robust Non-Destructive Inspection (NDI) techniques are employed to ensure they are eliminated from production components.

1. Introduction

Due to the introduction of composite main rotor blade (CMRB) technology for helicopters in the early 1980s [1,2] substantial developments have been made in providing erosion protection for these blades. In the case of helicopters, three main erosion strip materials are currently used, namely titanium [3], electroformed nickel [4] or corrosion resistant steel [5]. The particular erosion shield material used is primarily due to the design requirements of the specific blade. For example, in the case of the AW101, a medium lift helicopter, both titanium and electroformed nickel are used, the locations of which are shown schematically in Fig. 1.

Although the erosion shields primarily provide liquid (i.e. rain water) and solid (i.e. sand/debris) particle erosion protection to the CMRB this is not their only function. For example in the case of all-weather aircraft the erosion shields must also be thermally conducting (i.e. by providing de-icing capabilities through the use of imbedded heater mats) and have the ability to safely conduct a high electrical charge away in the case of lightning strike. In addition in the case of AgustaWestland Limited (AWL) designs they can provide up to 10% of the structural strength of the blade, hence they must have adequate tensile and fatigue properties. Finally as the erosion shields are bonded onto the CMRB a high level of profile conformance between the two elements must be achieved otherwise erosion shield debonding can occur. This is particularly so at the tip of the blade as AWL CMRB designs are primarily designed with complex anhedral or swept tip technology for enhanced performance [1], as developed by the British Experimental Rotor Programme (BERP).

Electroforming is a well-established electro-deposition process [6] for producing complex parts to close dimensional tolerances and exacting surface requirements making it a particularly attractive material to bond onto a close tolerance blade. However, components previously produced by this process route have largely been manufactured for non-structural applications.

Consequently, as the BERP tip erosion shields used on the AW101 are classified as critical, AWL undertook a comprehensive

* Corresponding author. Tel.: +44 1935 703381.
E-mail addresses: david.davies@agustawestland.com (D.P. Davies), steve.jenkins@agustawestland.com (S.L. Jenkins).
[1] Tel.: +44 1935 704169.

http://dx.doi.org/10.1016/j.msea.2014.03.122
0921-5093/

evaluation of the electroforming process, based on component cut ups and integral test pieces from serial manufacture, the results of which form the basis of this paper.

2. Manufacturing source

All of the AWL nickel electroformed erosion shields are manufactured by Doncaster's Bramah using the Ni-Speed [7] process. The Ni-Speed electroforming process utilises a concentrated sulphamate solution with cobalt additions, resulting in a nickel electroform containing approximately 8–10% cobalt, hence the electroformed nickel erosion shields used by AWL are in fact Nickel–Cobalt (Ni–Co) electroforms.

Due the critical nature of these parts each shield is manufactured to an individual sealed method of manufacture/data card and Westland Helicopters Material Specification WHMS 437, which details both the process controls and the mechanical property requirements that AWL stipulate for the electroformed nickel erosion shields. As the erosion shields are manufactured to a commercial in confidence process, details concerning certain proprietary information e.g. solution composition, solution temperature/pH, deposition time, current etc. cannot be divulged; however any variations were comfortably within the manufacturers defined processing limits for electroforming.

3. Experimental procedure

3.1. Test plan

In order to fully characterise electroformed nickel as an aerospace material AWL Materials Technology Laboratory undertook a comprehensive and detailed evaluation which was divided into three assessment phases, namely:

Phase I – To provide a basic understanding of the effect heat treatment can have on mechanical properties and microstructure of electroformed nickel.

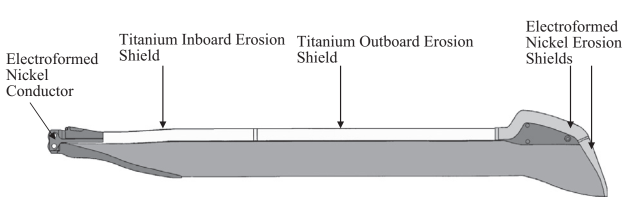

Fig. 1. Schematic diagram showing relative positions of the erosion shields.

Phase II – To establish and characterise any variation in mechanical properties present as a result of the electroforming process.

Phase III – To determine mechanical property variability obtained during serial production.

3.2. Shield configuration and cut up assessment

Although AWL currently used electroformed nickel on several aircraft, for Phases I and II the AW101 BERP tip erosion shields was used, details of which are shown schematically in Fig. 2, together with the integral test piece locations. In order to establish property variability as part of the Phase II trials, testing was carried out along the whole length (i.e. in both the span-wise [longitudinal] and chord-wise [transverse] directions) in three main positions from the trailing edge (i.e. up to 50 mm, between 50 and 100 mm and between 100 and 150 mm in the span-wise direction and between 25 and 125 mm in the chord-wise direction). In addition mechanical property differences between the upper and lower surfaces were also to be established as part of Phase II. As well as establishing defect characterisation, Phase III also included an assessment of the electroforming process variability by evaluating three different types of electroforming components used on the AW101 blade, as detailed in Table 1, together with the their integral test samples.

3.3. Mechanical property assessment

Tensile test pieces were manufactured according to WHPS336-MS2, the dimensions of which are given in Fig. 3a. Tensile testing was conducted according to the procedures specified in EN2002-1, under ambient conditions of temperature and humidity. As ductility measurements on a standard tensile specimen do not always fully reveal metallurgical changes, notched tension specimens conforming to the ASTM E338 were also manufactured and tested.

Table 1
Electroformed shields used on the AW101 main rotor blade.

Shield description	Nominal weight (kg)	Nominal size (m)	Nominal thickness (mm)	
			Leading edge	Trailing edge
BERP tip	3	1.3	1	0.5
Swept tip	0.95	0.85	1	0.5
Conductor root end	0.275	0.7	NA	0.7

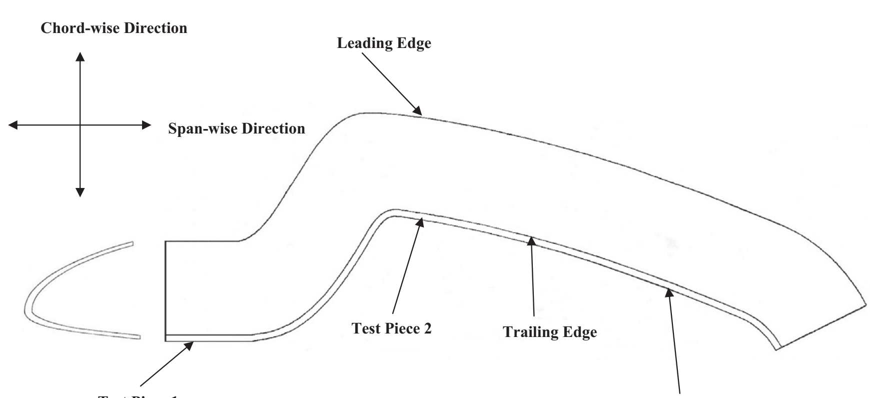

Fig. 2. Schematic diagram of the AW101 BERP tip erosion shield.