Int J Adv Manuf Technol (2013) 68:453–464
DOI 10.1007/s00170-013-4743-1

ORIGINAL ARTICLE

Investigating the effects of hard anodizing parameters on surface hardness of hard anodized aerospace AL7075-T6 alloy using fuzzy logic approach for fretting fatigue application

E. Zalnezhad · Ahmed A. D. Sarhan · M. Hamdi

Received: 17 February 2012 / Accepted: 7 January 2013 / Published online: 31 January 2013

Abstract Aerospace applications and energy saving strategies in general raised the interest and study in the field of lightweight materials, especially on aluminum alloys. Aluminum alloy itself does not have suitable wear resistance. Therefore, improvements of surface properties are required in practical applications, especially surface hardness when aluminum is in contact with other parts. In this work, first Al7075-T6 was coated using hard anodizing technique in different parameters condition and the surfaces hardness of hard anodizing-coated specimens were measured using microhardness machine. Second, fretting fatigue life of AL7075-T6 was investigated for both uncoated and hard anodized specimens at the highest surface hardness obtained. Third, a fuzzy logic model was established to investigate the effect of hard anodizing parameters, voltage, temperature, solution concentration, and time on the anodized AL7075-T6. Four fuzzy membership functions are allocated to be connected with each input of the model. The results achieved via fuzzy logic model were verified and compared with the experimental result. The result demonstrated settlement between the fuzzy model and experimental results with 95.032 % accuracy. The hardness of hard anodizing-coated specimens was increased up to 360 HV, while the hardness of uncoated specimens was 170 HV. The result shows that hard anodizing improved the fretting fatigue life of AL7075-T6 alloy 44 % in low-cycle fatigue.

Keywords AL7075-T6 alloy · Hard anodizing coating · Surface hardness · Fuzzy logic model

1 Introduction

Fretting fatigue is a phenomenon which occurs when the substrate is in contact with other parts while they are subjected to cyclic loads and sliding movements at the same time [1]. Fretting decreased fatigue life of materials drastically. The result of fretting in engineering components under cyclic load is the reduction of life by premature initiation and propagation of cracks within the contact area.

Aluminum alloy, which has superior mechanical properties, low cost, light weight, and reliabile, has been widely used for aircraft engines, fuselage, and automobile parts. Aluminum 7075-T6 alloy which is used in this research work has low specific weight and high strength to weight ratio and also high electrical and thermal conductance. This alloy is widely used in industry and in particular in aircraft structure and pressure vessels [2]; however, it is always subject to different working conditions. Wear and fretting normally begin when the substrate is in contact with other

E. Zalnezhad · A. A. D. Sarhan (✉) · M. Hamdi
Center of Advanced Manufacturing and Material Processing,
Department of Engineering Design and Manufacture,
Faculty of Engineering, University of Malaya,
Kuala Lumpur 50603, Malaysia
e-mail: ah_sarhan@yahoo.com

M. Hamdi
e-mail: hamdi@um.edu.my

E. Zalnezhad
Faculty of engineering, Islamic Azad University,
Chalous Branch, Iran
e-mail: erfan_zalnezhad@yahoo.com

A. A. D. Sarhan
Department of Mechanical Engineering, Faculty of Engineering,
Assiut University, Assiut 71516, Egypt

surfaces and rubbing each other under normal load, causing share force to act on the surface [3]. Aluminum alloy has problems of surface damage due to its softness and corrosion. Therefore, advances of surface properties are needed in practical applications.

Hard anodize coating is widely used for this purpose. This coating is also promising from the standpoint of the possibility of achieving high hardness, strength, and simultaneously good protective and decorative surface properties [4]. Anodizing is an electrochemical process for producing stable oxide films on the surface of metals. Anodic coating can be produced on aluminum by using a wide variety of electrolytes with AC, DC, or a combination of both in order to increase the hardness of metals.

All aluminum alloys do not accept hard anodize coatings equally well. Hard anodize coatings on alloys with high copper or silicon content tends to be porous and not very hard. Table 1 lists some of the aluminum alloys that are particularly troublesome; these should be avoided [3, 4]. Pure aluminum coating on the AL7075-T6 using magnetron sputtering technique is a method to create the possibility of hard anodizing performance [5]. To improve surface hardness, it requires investigating surface hardness of hard anodize coating at different parameter conditions. Hence, reliable systematic approaches to investigate the effects of hard anodize coating parameter for best surface hardness is thus required [5]. Soft computing techniques are useful when exact mathematical information is not available. The techniques differ from conventional computing in that it is tolerant of imprecision, uncertainty, partial truth, approximation, and metaheuristics [6, 7]. Components of soft computing include neural networks, fuzzy logics, evolutionary computation, chaos theory, and perceptron. Compared to other artificial intelligence methods, development of fuzzy logic is moderately easier and it does not need many software and hardware resources. Fuzzy logic is one of the soft computing techniques that play an important role in input–output parameter relationship modeling [8, 9]. The fuzzy modeling technique is used when subjective knowledge and suggestion by the expert are significant in defining objective function and decision variables. Fuzzy logic is preferred in investigating the coating performance based on the input variables due to nonlinear condition in the coating process [10]. In this research work, hard anodize coating on Al7075-T6 substrate was carried out in different parameter conditions. Each parameter has four levels which include voltage, temperature, solution concentration, and time. Fuzzy rule-based method was proposed to investigate surface hardness of hard anodize coating on AL7075-T6 alloy. The fretting fatigue test was performed on hard anodized specimens under the best parameter conditions that were achieved from the experimental results and fuzzy logic method.

1.1 Design of experiments

The most important stage in the design of an experiment lies in the selection of parameters and identifying the experimental array. In this experiment, with four parameters and four levels each, the fractional factors design used is a standard L_{16} (4^4) experimental array. This array is chosen due to its capability to check the interactions among parameters. The parameters and levels are assigned as in Table 2. The 16 experiments with the details of combination of the experimental levels for each parameter (A–D) are shown in Table 3.

1.2 Experimental details

1.2.1 Material

Aluminum 7075-T6 alloy was used in this investigation. The material's composition was obtained using EDX apparatus as illustrated in Table 4. From a number of tensile tests, the yield stress and ultimate strength of Al7075-T6 were obtained as: σ_Y=520 MPa and σ_{ut}=590 MPa, respectively. Two types of specimen (uncoated and hard anodized) for fretting fatigue test are used.

1.2.2 Specimen preparation and fretting parts fabrication

Fretting fatigue test specimens were machined with initial surface roughness R_a=0.6±0.1 μm by lathe turning (CNC LATHE MACHINE, Miyano, BNC-42C5). The round-shaped specimens used in this work were prepared in accordance with ISO standard [11]. Fretting fatigue pads were fabricated from AISI 4140 steel plate with hardness of 346 HV. Substrate material (179 HV) is softer than the pads but hard anodize coating (360 HV) is harder than pads. The

Table 1 List aluminum alloys which should be avoided to hard anodizing

Difficult Al alloys for hard anodizing
2011
2017
2024
7075
Cast and wrought alloys with Cu>4 % or Si>7 %

Table 2 Parameters and levels used in the experiment

Parameters		Experimental condition levels			
		1	2	3	4
A	Voltage (V)	10	20	30	40
B	Temperature (°C)	0	5	10	25
C	Solution concentration (%)	5	10	15	20
D	Time (min)	30	60	90	120