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Influence of temperature on galling resistance of SS 416

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ABSTRACT – The galling measurement was carried out on annealed SS 416 specimens under the self-mated condition as per the ASTM G196-08 test method. The test method appears to be superior to an older ASTM G98 because galling behaviour is prevailed by stochastic wear phenomenon.

1. INTRODUCTION

Galling is a form of surface damage arising between the sliding solids, distinguished by macroscopic usually localized, roughening and creation of protrusions above the original surface; it often includes plastic flow or material transfer or both [1]. Galling has been serious problems in various situation for example in medical instrument, food processing equipment, oil and gas exploration, automotive and nuclear industry. Where stainless steel is the material of choice for its relative ease of manufacture, high strength and stiffness, and excellent corrosion resistance, however, it has been found to be quite susceptible to galling [2]. Therefore Cobalt-based alloys are being considered as replacements for stainless steel in valve and pumps applications because of their best galling resistance. However in the nuclear industries alloys containing high level of cobalt are being scrutinized because wear and corrosion debris could be transported into primary cooling circuits. In view of this stainless steels are still being considered for nuclear applications.

The most widely used test procedure for the measurement of galling resistance of material pairs is ASTM standard G98 [1] and often referred to as the "button-on-block" test. It has been used for several decades to rank the galling resistance. In this method, the end of a cylindrical specimen is loaded against a flat plate or block. The block specimen is held fixed, while the cylinder is rotated for one revolution. Galling is determined by a simple visual inspection without the use of magnification. In the past few years, several papers described the significant problems with this test method [2]. Some of the issues discussed include stress concentrations in the contact region, lack of statistical analysis, and low number of replicates required in creating data sets. Additionally, the results of this testing method have been shown to vary widely in both intra and inter laboratory testing [2]. Very recently a galling test method developed by Hummel [2] has been adopted by the ASTM as a new standard for galling measurement (G 196-08) [3]. The test method uses two concentric hollow cylindrical specimens with the ends mated. One specimen is rotated about its axis and other is held fixed. According to ASTM G196-08, there is no single "threshold" of stress that characterizes galling behaviour. Galling is a stochastic phenomenon that can occur over wide range of stress values [4]. Further, galling resistance of material pair is strongly influenced by the temperature. Keeping in view of the above the objective of the present investigation was to measure the galling resistance of self-mated SS416 specimens at room temperature (RT) as well as at high temperature condition (300^0C) by using a mechanized type of galling tester. The results of self-mated galling tests on annealed SS 416 specimens are described in this paper.

2. EXPERIMENTAL DETAILS

The schematic diagram of the testing arrangement is shown in Fig.1a. The test method (ASTM G196-08) consists of two concentric hollow cylindrical specimens with ends mated with each other. This results in area contact in the shape of annulus. One specimen is rotated about its axis and the other is held fixed. An alignment pin being used in between the top and bottom specimen in the hollow space. This ensures proper alignment and concentricity between the mating surfaces (Fig.1b). The specimen geometry used as per the ASTM G196-08 and the area of contact surface is 94.96 mm^2. The care was taken for all the specimens to ensure the flatness were within 0.005 mm. The contact regions of the specimens were ground in an automatic surface grinding machine to get uniform surface roughness (R_a) and the measured R_a values were in the range of 0.25-0.35 µm. Before conducting the experiments specimens were cleaned thoroughly in an ultrasonic cleaner in an acetone bath and then dried. The specimens were mounted in the testing device and the load was applied lightly and the specimens twisted relative to each other approximately 45^0 to ensure proper seating of the wear surfaces. The desired load was then applied and lower specimen was rotated at 6 rpm. In the present study all tests were conducted for two rotation of the lower specimen (720^0). After the test both specimens were removed and examined for galling. A typical photograph of galled specimens is shown in Fig.2. If the specimen appear smooth and undamaged to the unaided eye then galling is said to not have occurred. At least one of the contacting surfaces should exhibit torn metal for galling to have occurred. According to ASTM G196-08, a minimum of 12 replicates are required to be tested at each load level. The frequency of galling is calculated by dividing the number of samples got galled to the total number of samples tested. For example, out of these 12 replicates, if 2 galled then frequency of galling at that load is 2/12 i.e. 0.166. A minimum of four load levels are required to perform the data analysis. At least two load levels shall be above the load where 50 % of the specimens would gall and at least two load levels shall be below the load where 50 % of the specimen would gall.

Fig.1 (a) Schematic view of the galling test arrangement (b) sectional view of the test configuration (1 ball bearing; 2 upper specimen; 3 alignment pin; 4 lower specimen; 5 contact surface).

Fig.2 Typical galled specimens

2.1 *Presentation of Data and Calculation of Galling$_{50}$ (G_{50})*

The data collected using this test method is plotted, a galling frequency against applied stress. The galling frequency quantifies the percentage of specimens that subjected to galling at each applied load. Each applied load levels tested result in a single data point on the galling frequency against applied stress diagram. After obtaining the data points a best fit curve can be used to fit the data points on the diagram. This is achieved by fitting a two parameter sigmoid equation to the data points. The two parameter sigmoid equation is represented in the following expression [3,4].

$$f = \frac{1}{1 + e^{-\left(\frac{\sigma - G_{50}}{b}\right)}} \qquad (1)$$

Where f is galling frequency, σ applied stress, G_{50} galling$_{50}$ value and b related to the steepness of the curve. The parameter G_{50} in equation (1) is the magnitude of the contact stress where, statistically, 50 % of the specimens experience galling [3]. The parameter G_{50} has been used in ASTM G196 [3] to characterize galling resistance of material pair. The galling$_{50}$ value is obtained graphically by finding the applied stress that corresponds to a point in the curve where the galling frequency is 0.50. Further details about the data analysis are given elsewhere in the literature [2-4].

3. RESULTS AND DISCUSSION

Fig.3 shows galling frequency as a function of applied stress at RT and elevated temperature condition. Fig.3 shows that galling is a stochastic phenomenon that can transpire at wide range of contact stresses. When the contact stresses is high, the probability that number of specimens get galled is higher than at low contact stress condition.

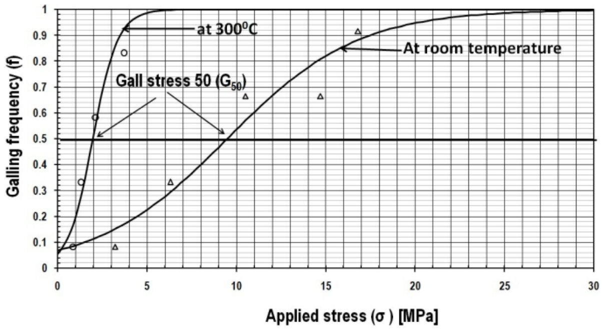

Fig.3 Galling frequency as a function of applied stress. Galling$_{50}$ is obtained by applying sigmoid fit to the test data.

It is clear that galling do exists at all non-zero stress levels. The probability of occurrence of galling increases continuously from zero and approaches to unity as the contact stresses increases. The galling resistance of material pairs tested was characterized with G_{50} and it is as per the ASTM G196 [3]. At room temperature G_{50} value was observed to be 9.48 MPa. On contrary at test temperature of 300^{0}C the galling resistance decreases (1.96 MPa) to the order of 5 (Fig.3). This is because the material pairs were subjected for thermal softening; therefore a severe plastic deformation was occurred at low contact stress level.

4. CONCLUSIONS

Galling was characterized with a parameter G_{50} at room temperature as well as at elevated temperature condition (300^{0}C). Test temperature has significant influence on the value G_{50} for the material tested.

5. REFERENCES

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