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Investigation and examination of residual stress in weld bead geometry

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ABSTRACT

Residual stresses occur in many manufactured structures and components. Large number of investigations have been carried out to study this phenomenon and its effect on the mechanical characteristics of these components. Over the years, different methods have been developed to measure residual stress for different types of components in order to obtain reliable assessment. The various specific methods have evolved over several decades and their practical applications have greatly benefited from the development of complementary technologies, notably in material cutting, full-field deformation measurement techniques, numerical methods and computing power. These complementary technologies have stimulated advances not only in measurement accuracy and reliability, but also in range of application; much greater detail in residual stresses measurement is now available. This paper aims to classify the different residual stresses measurement methods and to provide an overview of some of the recent advances in this area to help researchers on selecting their techniques among destructive, semi destructive and non destructive techniques depends on their application and the availabilities of those techniques. For each method scope, physical limitation, advantages and disadvantages are summarized. In the end this paper indicates some promising directions for future developments.

Keywords: WEDM, EDM, DOE, Drilling process.

[1] INTRODUCTION

The engineering properties of materials and structural components, notably fatigue life, distortion, dimensional stability, corrosion resistance, and brittle fracture can be considerably influenced by residual stresses. Such effects usually bring to considerable expenditure in repairs and restoration of parts, equipment, and structures. Accordingly, residual stresses analysis is a compulsory stage in the design of parts and structural elements and in the estimation of their reliability under real service conditions. Systematic studies had shown that, for instance, welding residual stresses might lead to a drastic reduction in the fatigue strength of welded elements. In multi-cycle fatigue (N>106 cycles), the effect of residual stresses can be comparable to the effect of stress concentration. Surprisingly, significant are the effect of residual stresses on the fatigue life of welded elements as regards relieving harmful tensile residual stresses and introducing beneficial compressive residual stresses in the weld toe zones. Currently, the residual stresses are one of the main factors determining the engineering properties of materials, pats, and welded elements, and should be taken into account during the design and manufacturing of different products. Although successful progress has been achieved in the development of techniques for residual stresses management, considerable effort is still required to develop efficient and cost-effective methods of residual stress measurement and analysis as well as technologies for the beneficial redistribution of residual stresses.

[2] LITERATURE REVIEW

TWI (The Welding Institute) carried out a comprehensive study of residual stresses in offshore girth-welded joints. It included a brief literature review, through-wall thickness residual stress measurements in 16-inch and 20-inch diameter pipes, numerical modeling of residual stress profiles, determination of an upper bound expression for the through thickness residual stress distribution for girth welds based on the revised database and assessment of the impact of the results on structural integrity assessment.

Kudryavatsev, et al.[4]ultrasonic technique proposed by Kudryavtsev al.the velocities of longitudinal ultrasonic wave and shear waves with orthogonal polarization are measured at a considered point to determinate the unit-and biaxial residual stresses. The bulk waves in this approach are used to determine the stresses averaged over the thickness of the investigated elements. Surface waves are used to determine the unit-and-biaxial stresses at the surface of the material.

Yates, et al.[5] have used an ultrasonic method to measure the non-uniform residual stresses in the transverse direction of the aluminium alloys. Aluminium alloys are widely used in the automotive, aerospace and other industries because of their high strength/weight ratio.

Leggatt, R.H., Smith, D.J., et al.[6] Development and experimental validation of the Deep Hole method for residual stress measurement. The technique involves drilling a reference hole through the component and accurately measuring its diameter before and after stress release by trapping coaxially around it. The difference between the measure diameters before and after stress release enable the original residual stresses to be calculated using elasticity theory. The technique used to measure bi-axial residual stress acting in the plane at 90^0 to the reference hole axis as standard.

[3] EXPERIMENTAL WORK

I. Procedure of experiment

Mild steel selected, is a high carbon and low chromium contents and is used for cold working processes. It is widely used in moulds and dies as drawing dies, forming rolls, powder metal tooling and blanking and forming dies. Three specimens were prepared for chemical composition by using the AMETEX SPECTRO MAX material analyzer.

The average values of chemical composition for the used material are given in table (1) Together with the standard, Mild steel according to ASTM A 681-76 standard specification steels (ASTM A 681-76). Two flat specimens were prepared for mechanical properties tests by using the universal testing machine type UNITED for tensile tests on the bases on ASTM-A370-77 steel standard for flat work piece (ASTM-A370-77), and for Rockwell hardness tests by using the hardness testing machine type INDENTEC.

The manufacturing of the work pieces is done by the wire electrical discharge machine (WEDM) type ACRA Brand and by a surface grinding machine then polished mechanically and manually by abrasive silicon carbide paper up to grade ASTM 3000. Measuring of the surface residual stresses before and after EDM machining and after the surface polishing were carried out.

Electrode's materials, Copper are selected. The copper electrode material was examined for chemical composition properties using the X-MET 3000TX HORIZONT metal analyzed the compositions obtained are: 0.006% Zn, 0.001% Pb, 0.0005% Sn, 0.005% P, 0.0002% Mn, 0.007% Fe, 0.004% Ni, 0.011% Si, 0.007% Al, 0.002% S, 0.005% Sb, and the remaining is 99.96% Cu. The electrodes were manufactured with a square cross-section of 8mm and 30 mm lengths. The prepared electrodes were polished as mentioned above.

Table (1): The chemical composition for the selected workpiece material and the equivalent standard mild steel.

Table 1:The chemical composition of workpiece materials.

le	%C	%Fe	%Mn	%P	%S	%Cr	%Mo	%Ni	%Co	%Cu
Tested Plates	1.51	0.174	0.264	0.014	0.003	12.71	0.555	0.158	0.013	0.099
Standard	1.40	0.60	0.60	0.03	0.03	11.00	0.70	1.00	1.10	0.306

Table (2): The mechanical properties of the used materials.

Ultimate Hardness Tensile stress (N/mm^2)	Yield strength (N/mm^2)	Elongation (%)
704.25	415.25	18.125

II. Design of Weld Joints

There are many aspects related with welding which influence the fatigue performance of a sound (defect free) weld joint such as welding procedure, weld bead geometry, weld joint configuration and residual stress in weld joint. These parameters affect the fatigue performance in four ways a) how stress raiser in form of weld continuities are induced or eliminated, b) how do residual stresses develop due to weld thermal cycle experienced by the metal during the welding, how are mechanical properties such as strength, hardness, ductility and fracture toughness of the weld joint influenced and how is the microstructure of the weld and HAZ affected by the welding related parameters.

III. EDM process

The selected EDM parameters are the pulse current Ip (8 and 22 A), the pulse on time duration period Ton (40 and 120 µs), the gap voltage Vp (140 V) and the electrode polarity (+). The EDM experiments were done on ACRA CNC-EB EDM machine. The kerosene dielectric was adjusting from both sides of the discharge area between the workpiece and electrode with a flashing pressure =0.73 bar (10.3 PSI).

Figure 1 Butt Joint

In the experimental work, two groups were designed. First group includes Butt Joint experiments by using the copper electrodes as shown in figure, where a new set of workpiece and electrode in each experiment. The second group consists of Lap Joint experiments by using the Copper electrodes with the same parameters. The EDM machining specimens and the used copper electrode is shown in figure.

Figure 2 Lap Joint

For minimizing the tensile surface residual stresses induced by the thermal stresses produced by the EDM machining, both groups of experiments with specimens were surface treated by using the electron discharge processes with 30, 45 and 60 minutes removal.

IV. Electron discharge Processes

The design of experiments (DOE) was used with a full factorial design method (FFD) and the three level factorial response surface methodology (RSM) for two experimental groups. The three EDM input parameters or factors designed as (X1, X2 and X3) are transformed into an output response variable, (Y). The designed EDM experimental matrix in a random manner with the selected factors (actual and coded) and the measured response (surface residual stress) both groups using the kerosene dielectric after using the EDM.

[4] RESULT AND DISCUSSION

The main goals are to minimize the values of response surface residual stresses with the same ranges of the selected EDM parameters, the electrodes types and the best electron discharge times as shown in table (8) .The solution found for the desirability process shows that the optimum predicted values of the surface residual stresses obtained when using the copper electrodes with pulse current about (8.0 A), pulse of duration about (120 µs) and removal time about (60 min.), gives the maximum compressive surface residual stresses (-831.986 MPa) with a maximum desirability ratio (0.968), as shown in table (9), the best solution found for the desirability process of the surface residual stresses when using the copper electrodes with pulse current about (21.583 A), pulse of duration about (119.105 µs) and removal time about (50.254 min.), gives the maximum surface residual stresses (-641.516 MPa) with a maximum desirability (1.0).

5. METHODS OF MEASURING RESIDUAL STRESSES

I. EDM-Hole Drilling method

In this study the EDM drilling process is used to measure the residual stresses of high-performance materials, whose stress state is difficult to obtain by a widely used technology called high-speed (HS) hole-drilling method (ASTM Standard E837). The experimental results in this method reveal that the stress measurement curves of both EDM conditions, which have the same EDM energy, are parallel with the ideal curve. Therefore, the results of EDM hole-drilling method can be positively calibrated by a constant, and it depicts the feasibility of residual measurement on material.

II. Finite element method

A finite element-based model for the electric discharge machining (EDM) process is presented. In this method we use process parameters such as power input, pulse duration, etc., to predict the transient temperature distribution, liquid- and solid-state material transformation, and residual stresses that are induced in the work piece as a result of a single-pulse discharge. An attractive feature of this method is its ability to predict the shape of the crater that is formed as a result of the material removal. But in this method, improvements to simulate the effects of multiple pulses hasn't been undertaken in the near future.

III. X-Ray differaction method

In this method parallel beam modification to determine the residual stress profile of electric discharge machined micro alloyed steel. Considerable amount of residual stresses is observed at the sub-surface layer and that the peak stresses were almost independent of the discharge energy and approaches the ultimate tensile strength of the material. The effect of increase in discharge energy was described as increase in depth where the peak residual stress occurs. This was related to the intensification of the surface cracking with energy. They observed lower stresses for dual phase samples compared to mic/ro alloyed one, although the difference in strength between these steels is not significant. They have concluded this situation as the influence of transformation stresses due to phase changes. The residual stress values increase from the bulk material to a maximum and then decrease again near to the surface. This decrease is related to crack formation since the residual stresses exceed the fracture strength of the material. It is noticed that the depth of the maximum stress value corresponds to the average depth of the thermal cracks network induced by EDM.

IV. Discussion

For the EDM machining using the copper electrodes and with further electron discharge processes, the best results for maximum compressive surface residual stresses obtained when using low values of pulse current (8 A), high pulse on duration (120 µs) and longer discharge time (60 min.), where the residual stresses reach maximum value of (-847.636 MPa).When working with EDM machining using the copper electrodes , the best results for maximum compressive surface residual stresses obtained with the same EDM parameters and electron discharge times as mentioned in item (1) above, where the residual stresses reaches a maximum value of (-637.073 MPa), and this means that copper electrodes improve the residual stresses by about (33%).

CONCLUSIONS

An analytical study concerning the misalignment effect on capillary compensated hole-entry hybrid journal bearing with double row of twelve holes in each row (symmetric configuration) operating with micropolar lubricant has been presented in this dissertation work.

Based on the numerically simulated results the static and dynamic characteristics such as pressure distribution, minimum fluid film thickness, stiffness coefficients, damping coefficients, critical mass and threshold speed have been evaluated for various values of micropolar and misalignment parameters.

The following conclusion can be drawn from the results presented in this study:-

In the case of Newtonian lubricant, the maximum pressure ($\overline{P}_{max}$) is observed to be increased for both aligned and misaligned conditions with restrictor design parameter ($\overline{C}_{S2}$), whereas for micropolar lubricant maximum pressure ($\overline{P}_{max}$) increases with the increase in value of restrictor design parameter ($\overline{C}_{S2}$) upto 0.1 thereafter it decreases slightly.
Minimum fluid film thickness ($\overline{h}_{min}$) is observed to be decreased in misaligned condition for both the cases i.e Newtonian and micropolar lubricants as compared to aligned condition with increase of restrictor design parameter ($\overline{C}_{S2}$).

In case of Newtonian lubricant with aligned condition, direct stiffness coefficient ($\overline{S}_{xx}$) increases with increase in the value of restrictor design parameter ($\overline{C}_{S2}$) up to 0.1, thereafter it decreases. For the case of micropolar lubricant with misalignment it decreases with increase of restrictor design parameter ($\overline{C}_{S2}$).

The value of cross stiffness coefficients ($\overline{S}_{xy}$) is found to be increased for Newtonian lubricant as the misalignment is introduced. While its value for micropolar lubricant with misalignment condition is found to be decreased as compared to Newtonian lubricant with aligned journal.

In case of Newtonian lubricant, the direct damping coefficient ($\overline{C}_{xx}$) increases for misaligned condition as compared to aligned condition but in case of micropolar lubricant, it decreases for misalignment as compared to aligned condition.
In case of misalignment, the value of cross damping coefficients ($\overline{C}_{xy}$) lies in positive region for both micropolar and Newtonian lubricant, whereas in aligned condition it is observed to be negative.

For Newtonian lubricant with aligned condition, the value critical mass (M_c) increases with increase in restrictor design parameter ($\overline{C}_{S2}$) up to 0.1, thereafter it sharply decreases .As the misalignment is introduced M_c increase with the increase the value of $\overline{C}_{S2}$ up to 0.15, thereafter it has negligible variation with restrictor design parameter ($\overline{C}_{S2}$). For micropolar lubricant, the critical mass(M_c) is lower in misaligned condition as compared to aligned condition at restrictor design parameter ($\overline{C}_{S2}$= 0.1).

For Newtonian lubricant, threshold speed ($\overline{\omega}_{th}$) is observed to be increased with misaligned condition as compared to aligned condition. The maximum increase in threshold ($\overline{\omega}_{th}$) is 73% at restrictor design parameter ($\overline{C}_{S2}$= 0.3). In the case of micropolar lubricant, threshold speed ($\overline{\omega}_{th}$) decreases with the presence of misalignment as compared to the aligned condition and the maximum reduction is observed to be 7% at restrictor design parameter ($\overline{C}_{S2} = 0.15$).

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