Investigation of surface induced-residual stresses due to shot peening using needle probes technique

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Hammer peening is an important surface work hardening process widely used in industries for fatigue retardation of mechanical parts. The constructive effect extent of hammer peening process on material properties and the residual stresses inherited from the processing history of the component, however, are dimmed by the degree of favorable compressive residual stresses or dislocation density introduced in the material. Investigating the extent to which hammer peening process may result in positive compressive residual stresses via experimental evidence will be the purpose of the present study. The magnetic signature of a ferromagnetic steel is highly dependent on the residual stress distribution. This observation constitutes the fundament of several micro-magnetic non-destructive testing methods. In this study, the micro-magnetic needle probe characterization method is used to sensor the local magnetic property variations due to the hammer peening process. Then, a magneto-mechanical model of the subject material due to shot peening surface induced-residual stresses is introduced based on the Jiles-Atherton-Sablik (JAS) model. This study worth as a validation of the needle probe method as a simple way to check the conformity of the hammer peening treatment. Coupled to simulation results, residual stress estimations can also be provided.

***Index Terms*— Magneto-mechanical effects, Magnetic sensors, Nondestructive testing, Stress**

I. Introduction

Over the years, shot peening has been a successful method in preventing, or substantially retarding stress corrosion cracking, crack initiation and growth, and other fatigue phenomena in engineering components [1]. This process aims at creating substantial levels of compressive residual stress in thin near-surface layers of material due to tensile plastic deformation of a surface layer [2].

Hammer peening is a shot peening process which aims at improving the fatigue strength of components based on the principle of preventing dislocation movement in the surface layer either by a local increase of the yield strength in the outer surface, the introduction of favourable compressive residual stresses or by reducing the surface roughness [3]. Applications of hammer peening to improvement mechanism of fatigue strength of weld joints by introducing large compressive stresses which tend to dim the harmful tensile residual stress state arising from the welding process are recurrent in the literature [4].

However, little attention has been laid on the constructive effect extent of hammer peening process on material properties and the residual stresses inherited from the processing history of the component. The disproportional effect under tensile and compressive stresses (as the case under shot peening) at the result of the magnetic properties' asymmetry behaviour of ferromagnetic materials, referred as the Villari effect [5] results from stress demagnetization at the vicinity of the elastoplastic indented area [6].

Recent evolutions in the field of non-destructive testing and evaluation (NDT&E) led to the development of magnetic-based NDT techniques making use of the fundamental coupling features between stress and magnetic field within small magnetic domain structures of ferromagnetic materials [7]. The current applications of Werner's equivalent one-turn coil invention [8] using a pair of needles in electrical contact with the test material allows to measure local micro-magnetic properties with satisfactory results.

This paper uses the needle probe method to investigate on the compressive residual stresses' effects on identical strips peened surfaces of wrought iron material due to single shots of variable amplitudes using a calibrated impulse hammer. A modified JAS model was used to numerically compare the experimental data.

II. Experimentation

A. Specimen treatment

For these experiments, three strips of equal dimensions (120 x 30 x 0.25 mm) extracted from a single wrought iron sheet were analysed for residual stresses (see Fig 1). Each oblong strip was marked lengthwise with sample lines at 1 mm step over a distance of 30 mm enclosing of the indented area. The sample line located at the centre of the indented area was referred as the reference position.

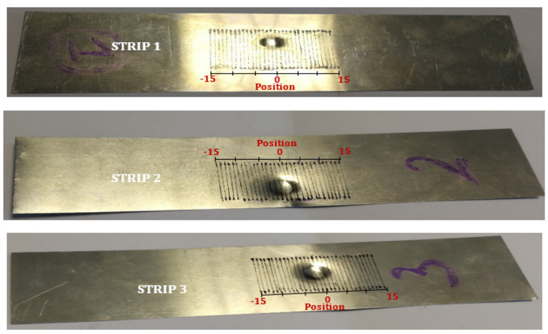

Fig. 1. Wrought iron strips subjected to surface treatment by hammering.

The induced-residual stresses were as a result of a single shot carried at the middle of the specimen using a calibrated impulse hammer 5850B. The shot intensity due to the applied input impulse varies per test material; strip 1 bears the least shot intensity while strip 2 the highest shot intensity.

III. RESULTS AND DISCUSSION

The needle probe method was used in order to evaluate the residual stress layers induced by hammer peening. A comparison of local magnetic permeability of all treated specimens is presented in Fig. 2. The induced-residual stress as a result of the hammer peening process causes localized compressive and tensile effects at the top and bottom sub-surfaces of the material respectively. It is observed that strip 1 shows magnetic symmetry for top and bottom surface measurements.

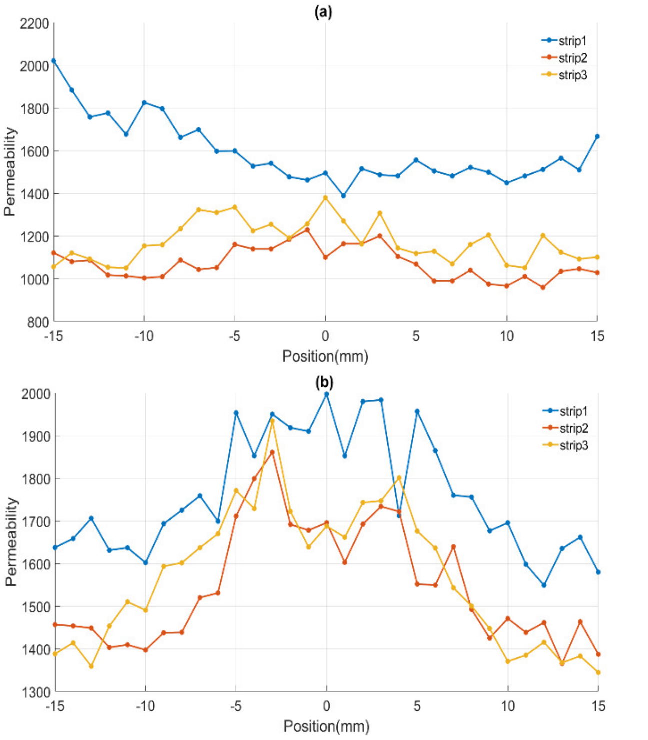

Fig. 2. Lengthwise comparison of permeability of the three strips: (a) top surface, (b) bottom surface.

On the other hand, further increase in peening intensity – case of strips 2 and 3 leads to further compression and tension on the material surface giving rise to significant permeability dips (Fig. 2b) and shallow ascents (Fig. 2a) at the bottom and top surfaces respectively, for maximum surface compressive stresses at the reference line. The compressive stress incurred during hammer peening in polycrystalline media causes random magnetization of grains due to misalignments and distortion. Meanwhile, grains' deformation under tensile stress tend to be attenuated by the entirely elastically deformed component. This leads to slight convergence of the magnetization in the material. These shallow growths and dips in permeability also referred as asymmetry behaviour of magnetic properties under tensile and compressive stress [9] accounts for the effect of stress demagnetization.

The JAS magneto-mechanical model of the sample materials due to peening induced-residual stresses was used to match the experimental data. The idea behind this simulation work is to provide an estimation of the average residual stress due to the hammer shot. In [30], Sablik et al. proposed an extension of the classic Jiles-Atherton model for the consideration of the residual stress influence. The main JA's model equations are:

$$M = M_{rev} + M_{irr} \quad (1)$$

$$H_e = H + \alpha . M \quad (2)$$

$$M_{rev} = c(M_{anh} - M_{irr}) \quad (3)$$

$$\frac{dM_{irr}}{dH_e} = \frac{M_{anh} - M_{irr}}{k\delta} \quad (4)$$

M_{rev}, M_{irr}, M_s, M_{anh}, are respectively the reversible, irreversible, saturated and anhysteretic magnetization contribution. H_e is the effective excitation field and α, c, k, δ, a, the model parameters. In the extended JAS version, an additional term in the effective field in response to the effects of applied stress on the ferromagnetic material is proposed by

$$H_e = H + \alpha M + H_\sigma \quad (10)$$

A comparison of the measured and modeled hysteresis curve at 1 mm displacement for stripe 3 is presented in Fig. 10.

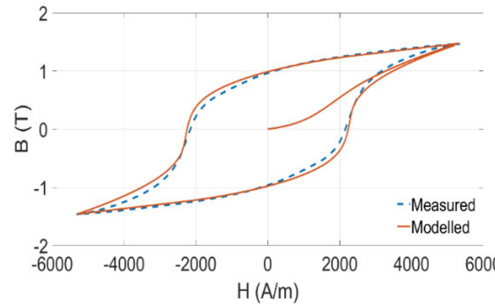

Fig. 3. Comparison of measured and modeled hysteresis curves at 1 mm Displacement for strip 3.

The simulation results confirm that a mechanical stress contribution is necessary to correctly simulate the magnetic behavior of the impacted zone. An average residual stress of 5. 106 Pa is obtained but this is just an estimation and due to the inhomogeneous distribution, it is complex and hazardous to physically interpret this result. A space discretization of the residual stress is required to improve the simulation; this will be proposed in a future work

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