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Study on Effect of Electromagnetic Field on The Fracture Properties of Steel and Copper

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Abstract- Different environment such as temperature, electric field, magnetic field, etc, influences the mechanical properties of metals. And many researchers are working on this area to improve the properties of materials for the optimum performance. This paper reviews the electromagnetic effect on the properties of steel and copper. The studies presented in this review referred to the effects and influence of magnetic field on mild steel and copper on the basis of behaviour of magnetic field intensity (lines) inside these materials leads to the martensitic transformation in which the structure changes from Face Centered Cubic to Body Centered Cubic (FCC~BCC) lattice structure. On the other hand, if an alternating magnetic field is created around a 'copper wire through it' for more than 20 hours, fracture toughness decreases. Increase in temperature increases the resistance which affects the performance of the metals.

Keywords: *Magnetic field, fracture properties, .*

I. Introduction

Developing countries used large number of small electric motors. The material of the rotors of small electric motors used in working machines should be such that the energy loss due to hysteresis effect is minimum. Under electromagnetic environment different materials behave differently. The engineering aspects involved while selecting the rotor shaft should also consider the energy considerations. In this study work is carried out to know, how the electromagnetic environment influences the mechanical properties specially the dynamic properties such as the repeated loading which the material has to undergo-such that the designers can make use of the generated information in proper selection of candidate materials for optimum performance.

It is very important to see that in the recent years, the use of various metals in magnetic field environment such as motors, generators, fusion reactors, superconductors, magnetic levitation trains etc has increased tremendously [2]. It has created a need for reliable structure to support the high Lorentz forces produced by the magnetic field. So it is important to design such structures, there is a need to consider the possible influence of the magnetic field on the mechanical properties of candidate structural materials. To make the structure of above-mentioned devices, copper, aluminum alloy, and steel are the most widely used material.

It is well known [1-6] that the magnetic field affect the properties of ferromagnetic materials. The magnetic field promotes martensitic transformation [11] in steel which changes both the tensile properties and fracture properties [1-5]. With the effect of magnetic field on the tensile properties rate of work hardening increases, which increases the ultimate tensile strength, while decreases the ductility. The fatigue properties may increase or decrease depending on the stability of material and the intensity of magnetic field for ferromagnetic material [1].

II. Literature Review

The better your paper looks, the better the Journal looks. Thanks for your cooperation and contribution.

In this literature review detail study relevant literature concerning our topic. Primarily we will discuss the research work done by various researchers regarding effect of electromagnetic field on fracture properties of metals. The external parameters generally considered in the plastic deformation of metals and ceramics are the temperature, pressure or stress and time. Usually neglected are the effects of the electric and magnetic fields.

Zhao Yong et al [1], suggested in his paper that metal fatigue and damage can be slowed down with the use of an alternating magnetic field. Through the study of dissipative structure theory, a new idea has been formed, it is suggested that under some specific conditions and using some specific methods which can promote the formation of dissipative structure- a metal system may be changed from a chaotic state to a new state of order. In this way, metal fatigue and damage can be checked and even eliminated.

He showed in his work that the fatigue life of A3 steel could be increased 4 times by the application of magnetic field. The result obtained by him are shown in table given below-

Table 1 The test Results[1]

	Open air			Magnetic field		
	Specimen No.			Specimen No.		
	1	2	3	1	2	3
Life cycle	77830	94050	77880	296980	339550	285610
Average life	83256			307380		

Y. Shindo, D. Sekiya [2], revealed in their paper that, the magnetic field effect can increase the value of the stress intensity factor. They consider a problem of soft ferromagnetic isotropic

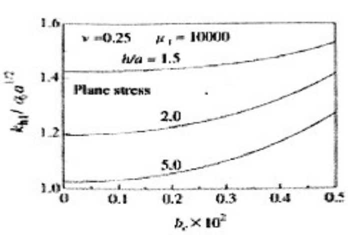


FIG 1(a)
Stress intensity factor versus magnetic field(h/a = 1.5,2.0,5.0)

linear elastic strip with central crack under magnetic field, and show the effect on stress intensity factor (shown in fig 1 (a) and fig 1 (b).

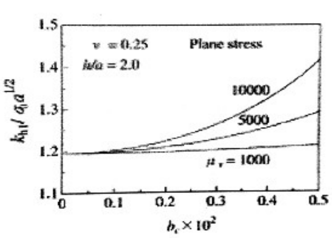


FIG 1(b) Stress intensity factor versus magnetic field (μ_r = 100,1000,10000)

S.-X. Zhao, paper [3] studied the eccentric crack problem in soft ferromagnetic elastic strip under uniform magnetic field. In this paper the result indicate that the stress intensity factor increases slowly when the magnetic induction is smaller than about half of its corresponding value, and continue to increase at a high rate as the magnetic induction increases.

D. N. Fang, paper [4] studied the effect of magnetic field on the fracture toughness of soft ferromagnetic materials using experimental techniques and theoretical models. The results indicate that there are no significant variations of the measured fractured toughness of the manganese-zinc ferrite ceramic in the presence of the magnetic field.

Y Zhang, [5) studied the high temperature tempering behavior in a structural steel under high ic field. The purpose of his work is to investigate the growth behavior of cementite in a structural steel under a high magnetic field. Evidence of the influence of the magnetic field on recovery and orientation distribution characteristics of the matrix. Insight into these issues is of great theoretical significance.

The mechanical properties of specimens[5] tempered at 600°C are given in table 2 It is seen that the tensile strength of the specimens tempered under magnetic field are slightly higher than those for the non field ones where the impact toughness remains almost unchanged in the two cases.

Table 2 Mechanical properties of steel tempered at 600^0C for 1 hr without and with a magnetic field [5]

Field Induction	Yield Strength (MPa)	Tensile Strength (MPa)	Impact Toughness (MJ/m^2)
0 T	935.33	1033.73	0.974
14 T	945.33	1040.17	0.968

In D. Binesti [12] paper, core losses of an 18.5 kW asynchronous motor were measured and computed, by means of a suitable electromagnetic fields package, improved for core loss calculation. The results show that a 1 to 3 % improvement in efficiency is possible by replacing the conventional soft laminations by new materials.

Fundamentals of Fracture Mechanics

It is now well known to designers that fatigue accounts for a majority of material failures. Fatigue failure is characterized by slow but steady crack propagation in weaker sections of a structural component under fluctuations of load, temperature, or other stress producing parameters. Traditionally, the fatigue strength of a component is expressed in terms of the number of cycles to failure for a given level of stress fluctuation. This description ignores the mechanics of crack initiation and its subsequent growth with time. Modem fracture mechanics provides the designer with more reliable predictions of fatigue life.

The fundamental principle of Fracture Mechanics is that the stress field ahead of a sharp crack in a structural member can be characterized in terms of a single parameter, K, the stress intensity factor. This parameter, K, is related to both the nominal stress level (σ) in the member and the size of the crack (a).

Thus members or the test specimens, that have flaws can be loaded to various levels of K, either by increasing 'σ' and/or 'a', analogous to the situation where various unflawed members can be loaded to various stress levels, σ.

Since the failure of most equipment or structural members is caused by the 'propagation of cracks to a critical value, an understanding of the magnitude and distribution of the stress field in the vicinity of the crack front is essential to determine the safety and reliability of equipment and structure.

Definition of 'fatigue'

ASTM defines 'fatigue' as 'The process of progressive localized permanent structural change occurring in a material subjected to the conditions, which produce fluctuating stresses and strain at some point or points and which may culminate in cracks or complete fracture after sufficient number of fluctuations'.

Fatigue Crack Growth under Constant Amplitude Loading

For structural materials, fatigue crack propagation has been shown to be crack extension in every load cycle (striations, fractographic observations by electron microscope) (Schijve 1979) if the stress range and ratio are sufficient. A cyclic loading of the type shown in Fig. 3 will cause a crack to propagate across a metal plate if the stress range and stress ratio are sufficient. The crack will propagate some incremental amount with each application of a load cycle.

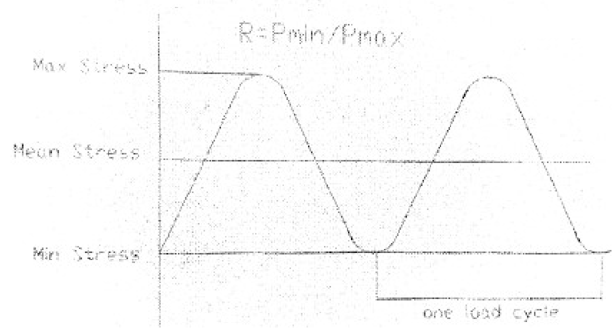


Fig3. Constant amplitude cyclic stress

σ_{max} = Maximum stress,

σ_{min} = Minimum stress

Mean stress, $\sigma_{min} = (\sigma_{max} + \sigma_{min})/2$

Stress range, ~O' = (σ_{max} - σ_{min})

Stress ratio, $R = \sigma_{min} / \sigma_{max}$

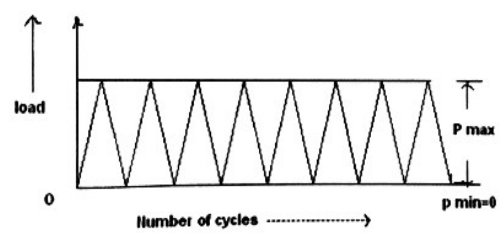


Fig 4 Typical load cycle for constant amplitude loading

The above figure shows a typical constant amplitude loading. Maximum load is P_{max} and minimum load is P_{min}. (P_{min} - 0 here).

Electron Microscopy The Scanning Electron Microscope (SEM) is a vital and essential tool for fracture research. The SEM has a broad range of magnification levels from lOx to 30000x with a large depth of focus compared to optical microscopy. Specimens are inspected directly and are prepared for the SEM easily and non-destructively. Fractographs produced by the SEM are unique and easy to analyses in that they have a 3D appearance. Samples to be analyzed using the SEM cannot be very large (although larger SEMs do exist) and in some instances it may only be possible to analyze a fracture surface macroscopically due to its size unless it is possible to segment the specimen to a size that will fit in the SEM. Although cutting a specimen up can destroy features on a fracture surface that would be vital in determining the cause of failure.

The aim of fractography is to analyse the fracture surface in order to gain some useful information about the material and its failure. It is important so that the fracture mechanism can be determined. This is also useful in forensic engineering and establishing the cause of fracture. It is possible to use this information to prevent potential future failures and advance materials technology. For example fracture tests are performed and analysed for research purposes in order to determine the materials properties. However service failures can be analysed for insurance and accountability purposes to determine the cause of failure.

Fractography is performed on a variety of levels depending on the specific purpose. Optical fractographic techniques include macro fractography which is used to describe visual fractal analysis whereas micro fractography describes low magnification (<= x25) analysis. Electron fractography uses an electron microscope for very high magnification and high resolution fractographs.

Fracture Mechanisms

A fracture surface should be treated as a record of the history of a component failure. Detailed within the fracture surface is evidence of loading history, environmental conditions and material quality [13]. For the purposes of this resource, fracture surfaces are classified as brittle, ductile and fatigue although some specimens may clearly fit into a number of fracture categories. For example a fatigue failure fracture surface may exhibit a ductile final fracture region. This will be taken into account and the fracture image will appear in all of the categories where it is relevant.

Brittle Fracture Brittle fractures have no plastic deformation and are usually characterized by a lack of necking with smooth/shiny facets (as shown below), an appearance associated with fast crack growth [14]

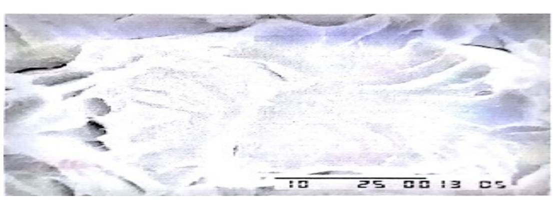


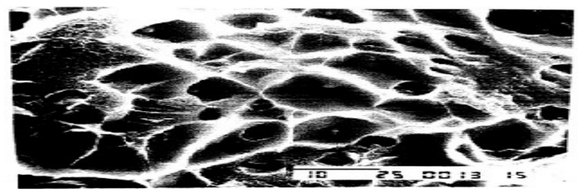
Fig 5 SEM image of brittle fracture in plain carbon steel

A brittle failure mode such as cleavage or inter granular (fracture along the grain a macroscopic level, chevron or radial markings may be boundaries) is seen, On observed

as shown below.

Fig 6 Radiating Ridge Fracture Surface (Callister, W.D., Page 186)

Ductile Fracture Conversely ductile fractures can be characterized by necking of the material due to plastic deformation. A fibrous/rough and dull fracture surface can be observed associated with slow crack growth. Plastic deformation is produced by a ductile failure mode such as micro void coalescence leading to dimple rupture which can be seen below. Failure at the edges of the sample



occurs at 45° to the loading direction due to the maximum shear stress being at 45° to the loading stress.

Fig 7 SEM Image of ductile fracture in plain carbon steel

Ductile tensile failure begins with uniform plastic deformation leading to localised micro void coalescence and then dimple rupture in the necked region which experiences a tri-axial stress state on formation of the neck. Dimple rupture leaves pits and holes on the surface structure.

Factors affecting the failure mode are:

- Material Microstructure
- Temperature
- Strain Rate
- Environment (leading to corrosion)

Material inside a magnetic field Suppose a material placed in an external magnetic field. If the material is paramagnetic, a small magnetization occurs in the direction of the field. If it is ferromagnetic, a large magnetic field occurs in the direction of the field and if the material is diamagnetic a small magnetization occurs opposite to the direction of the field. The lines of the magnetic field B, thus, become denser in a paramagnetic material but become less dense in a diamagnetic material.

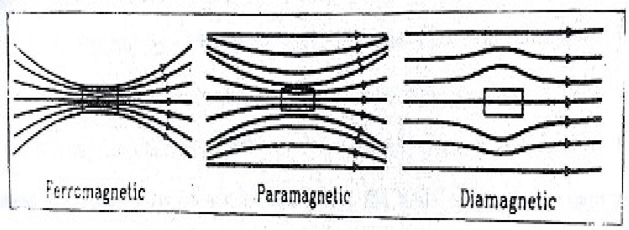


Fig 8 Showing the magnetic field lines inside material when placed in a magnetic field

The magnetic material is a small but positive quantity (=10-3 to 10-5) for paramagnetic substance; of the order of several thousands (positive) for ferromagnetic materials and small but negative for diamagnetic substances. The relative permeability)..Ir = I + X is slightly more than I for ferromagnetic material and slightly less than I for diamagnetic material [6].

Conclusions: From the above study, Fatigue life of IS-l 020 steel is increased due to magnetic field effect. These effects have been justified on the basis of material behaviour inside the magnetic field and the martenstic transformation in mild steel. SEM is used to analyse the fracture surface in order to gain some useful information about the material and its failure for example in forensic engineering and establishing the cause of fracture. SEM analysis was done to find out the existence of the extent of micro pores & voids. Encouraging results were obtained which proved that not only micro pores & voids exist in the new contact wire but also its manifestation lies in the form of cracks in the used copper wire. Fracture toughness value of the copper wire decreased due to electromagnetic effect. So, it can be concluded that there is a need of intensive study to redefine the design procedure of the contact wire used for electric traction from the point of view of adding the concept of fracture mechanics to it and for design of core which are used in small electric motors so that reduce the losses and consume optimum power.

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