Ain Shams University
Faculty of Engineering

MECHANICAL BEHAVIOUR OF METALLIC MATERIALS UNDER TORSIONAL IMPACT LOADING

By

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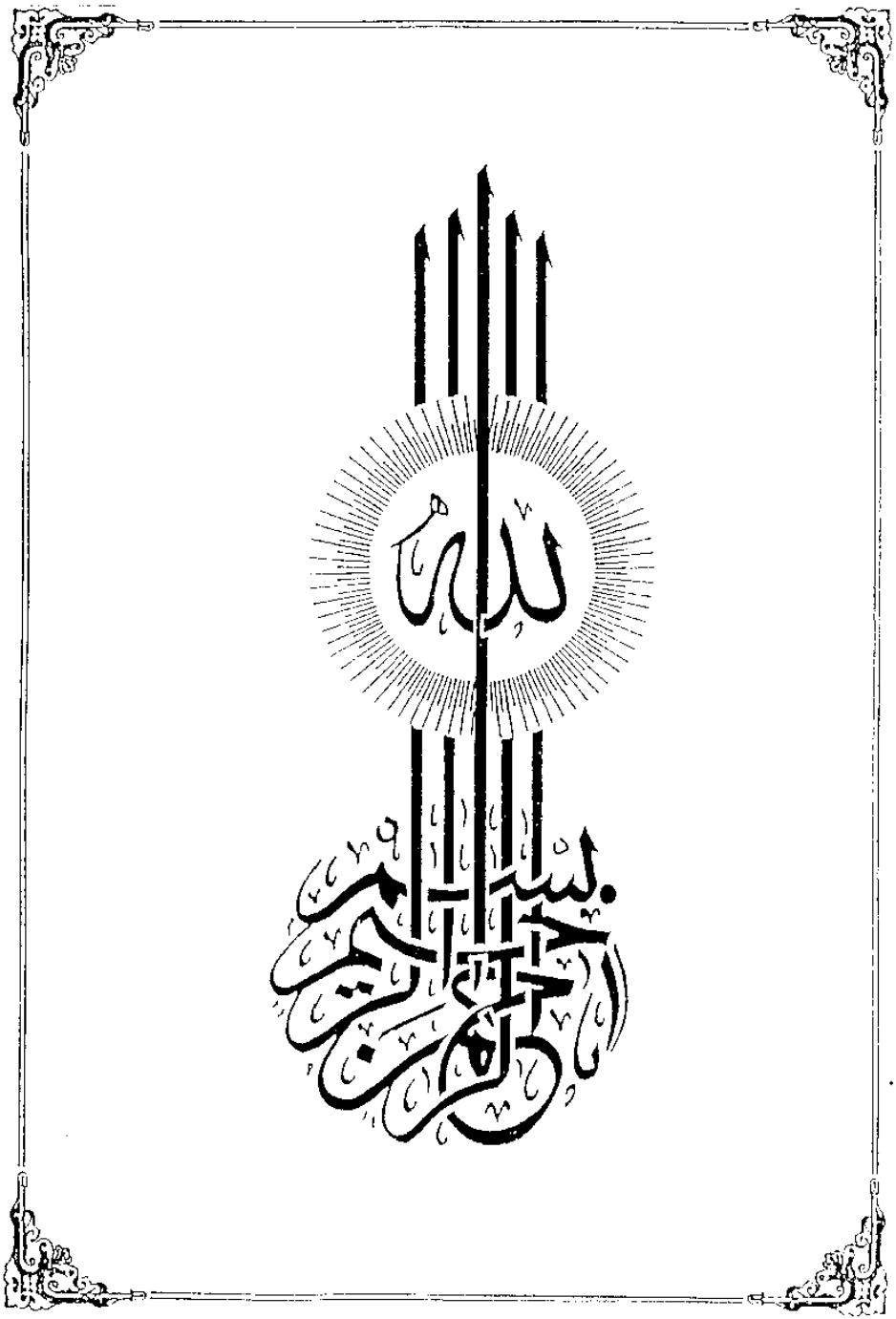

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STATEMENT

This dissertation is submitted to Ain Shams University for the degree of Doctor of Philosophy in Mechanical Engineering.

The work included in this thesis was carried out by the author in Lehr und Forschungsgebiet Werkstoffkunde RWTH Aachen University, Aachen, Germany and in Design and Production Engineering Department, Ain Shams University, Egypt, from 1990 to 1994.

No part of this thesis has been submitted for a degree or a qualification at any other University or Institution.

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ABSTRACT

A considerable amount of investigations has recently been presented dealing with the mechanical behaviours of some types of cast iron, especially spheroidal graphite cast iron (GGG) and Vermicular (compacted) graphite cast iron (GGV), due to their following advantages compared to gray cast iron:

- Higher tensile strength,
- Higher ductility and toughness,
- Less section sensitivity

However, further data is necessary from the point of view of practical use, for instance regarding the behaviour of these materials at low temperatures. In addition, knowledge of rate-dependent behaviour over a wide range of strain rate and temperature is necessary in formulating constitutive equations as well as in determining the predominant mechanisms responsible for this material behaviour.

This investigation deals with the mechanical behaviour of these materials under the condition of static and impact loading at low temperatures. Moreover, pure iron (Armco iron) was tested for comparison purpose. Split Hopkinson bar apparatus for torsion was modified to be used for reloading impact torsion, reverse impact torsion and for quasi static torsion tests. A modified thin walled tubular specimens were used for torsion. The tests were carried out on three metallic materials spherical graphite cast iron (GGG-40), Vermicular graphite cast iron (GGV-30) and Armco iron as a reference.

The tests were carried out at different temperatures ranging from 93 K up to room temperature in order to find out the influence of temperature on the mechanical behaviour of these materials. Strain rate up to ($3x10^3$ s^{-1})was achieved. Also static tensile tests were carried out on the tested materials.

The fracture surfaces were evaluated using the scanning electron microscope (SEM), while the optical microscope was used to study the microstructure in the deformed region of the tested specimens. Also the adiabatic shear band phenomena was investigated on the macro and micro scales, and thermal softening due to the adiabatic shear band was predicted mathematically.

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A structure mechanical model, based on Macherauch and Voehringer constitutive formula, was applied on the experimental results in order to predict the constant parameters for the tested materials under different temperatures and loading rates.

Based on the results of the present work the following conclusions can be drawn:

1. Below room temperature both types of tested cast iron are closely similar with respect to the relation between thermal part of shear stress and strain rate. However Armco iron is more sensitive to change in temperature within this range than both types of cast iron.

2. Increasing the strain rate which leads to temperature concentration, increases the possibility of strain localization or the adiabatic shear bands phenomenon to occur. Armco iron shows strong tendency to form adiabatic shear bands.

3. Fairly good agreement is observed between the experimental results of Armco iron and the calculated shear stress- strain curves with adiabatic shear bands factor.

4. Under loading and reverse loading of Armco iron, the final strain distribution is affected by the strain rate as well as the number of repeated shocks. The deformation has occurred in different regions along the specimen length.

5. The structure of mechanical model according to Macherauch and Voehringer is applied on the experimental results to predict the parameters of the tested materials, and therefore the model can be used for the three tested materials.

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INTRODUCTION

The term "cast iron" identifies a family of engineering materials with a wide range of microstructures and properties. Moreover, with the development of new techniques for graphite morphology control, cast irons have joined the category of engineering materials. It is well established that, graphite morphology is a primary determiner of a range of useful properties, from strength and ductility to thermal conductivity. Also, cast iron can be treated as a two-phase composite material comprising anisotropic randomly oriented graphite particles embedded in a steel like matrix.

It is well known that the importance of cast irons as engineering materials cannot be disputed (2). There are some applications in which cast iron components, especially spheroidal graphite cast iron, may replace components of plain or even medium carbon steels (3,4).Spheroidal graphite cast iron (GGG) is among other suitable for pipelines. It has good mechanical properties, proper ductility and corrosion resistance. Several important pipelines have been in use for many years all over the world, for water, gas at high pressure, as well as for heating, loading and unloading tankers. Also beside the low Brinell hardness the presence of graphite in this cast iron makes machining easy. It was found to be suitable for use in agricultural and automobile components, that may be used at low temperatures, and for refrigeration equipments.

In recent years a new group of materials has jointed the family of commercially produced cast iron. These are known as Vermicular (compacted) graphite cast irons (GGV). Wide interest in this material has only been shown in recent years, while it proved many advantages in some applications. Some components from this material for trucks and tractors were produced since 1968 in Austria. The trial production of cylinder heads for high power diesel engines followed in 1970 in west Germany. Further field of applications are ingot moulds, slag buckets, engine and turbocharger housings, exhaust manifolds and vehicles and railway trains, pressure tight components for hydraulic equipment and many other applications. Vermicular graphite cast

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iron has properties which lie intermediate between those of flake graphite and spheroidal graphite cast irons (103). Its mechanical properties are close to spheroidal graphite cast iron, while its thermal properties are similar to those of flake graphite cast iron.

Much of the current effort in metal plasticity is concerned with determining the influence of the rate of deformation and temperature on the flow stress. The mechanical behaviour of materials at high rates of loading is of interest from two points of view. Firstly, it helps the designer in selecting the suitable material for high rate of loading applications. Secondly, since the variation of stress-strain diagram with loading rate is related to relaxation processes taking place on a microscopic scale in the materials (8). Moreover in a very wide range of practical engineering applications, structural materials are subjected, either by accident or by design, to very high rates or impact loading leading either to catastrophic failure or to a corresponding high rate of straining (1).

Also the number of applications in which metal components and structures are required to withstand load at very low temperatures is increasing and considerable interest has arisen concerning the low temperature properties of metals (5). Electrical and chemical industries, as well as cooled containers, and pipelines require components for service at temperatures that are below zero for long periods . Recently, there has been renewed general interest in the low temperature properties of cast irons.

The main objective of the present work is to study the mechanical behaviour of some interesting types of cast iron as well as pure iron as reference, under impact torsion loading. A split Hopkinson bar apparatus for torsion test was modified to be used for reloading impact torsion, reverse impact torsion and for quasi static torsion tests. Thin walled cylindrical tube specimens with different gauge lengths were used. The present work gives impact shear stress-strain results for shear strain rates in the range 50 s^{-1} to about 3000 s^{-1}. These results were compared to those obtained at quasi-static strain rates of about 0.6 s^{-1}. To find out the influence of temperature on the mechanical behaviour of the tested materials., the tests were carried out under different temperature ranges from 93 K up to room temperature.

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In order to find out the effect of loading rate and temperature on the deformation process and the fracture behaviour, metallographic investigation was carried out on some tested specimens using scanning electron and optical microscopes.

Finally, a mathematical model was used to predict the parameters of the tested materials under different temperatures and loading rates. Another model was developed in order to describe the thermal softening occurring under high strain rates due to the adiabatic temperature increasing.

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CHAPTER I

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1. LITERATURE SURVEY

1.1 Materials response under impact loading

The response of materials and structures to various ways of loading and environmental effect is quite different (6). Among these effects are the state of loading i.e. static, dynamic, rate of straining, temperature ranged test, atmospheric and environmental effects. In this respect different mechanisms govern the deformation behaviour of materials within different strain rate regimes as shown in Fig. 1-1.

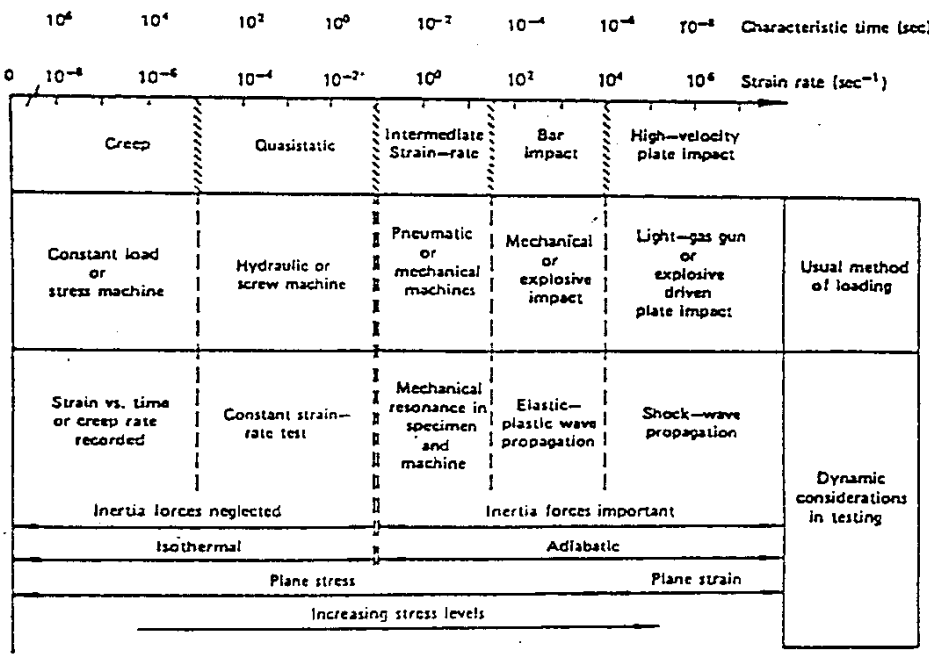

Fig. 1-1 Dynamic aspects of mechanical testing (6)

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