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Effect of multi-impacts on a PMMA sheet material

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ABSTRACT

When a specimen or component is subjected to repeated impacts it may eventually crack and fracture. A multi-impacts/impact fatigue study has been made for the first time on acrylic type PMMA (polymethylmethacrylate) sheet material with different type of notches and loading conditions. The study is conducted using a pendulum type repeated impact apparatus specially designed and instrumented for determining single and repeated impact strengths. Well-defined impact fatigue (S–N) behavior, having progressive endurance below the threshold single cycle impact fracture strength, with a limit, has been demonstrated.

1. Introduction

Repeated impact loads are considered to be one of the service loads acting on gear teeth and roller chains are well known as impact loads. Wheels and shafts of rail road train are said to be subjected to impact load when they run over switching points or when tires are flattened by braking action. Fatigue failures caused by repeated impact loading have frequently been reported. The increasing use of PMMA type acrylic sheet and rod materials for various structural and electrical applications have demanded with greatly improved performance to withstand repeated impact stresses under various notch and loading conditions. Failure of PMMA type acrylic materials under single and repeated impacts analogous to fatigue are of concern to the designer and users of various structural applications. For applicability in structure where PMMA sheets are subjected to repeated impact loading conditions it is necessary to predict the probable lifetime of such acrylic structures.

Studies on effect of repeated impacts/multi-impacts/impact fatigue began concurrently with those on conventional fluctuating stress fatigue, but the volume of work on multi-impacts reported in the literature has been small. Some preliminary studies on metallic materials revealed that the impact-fatigue strength is lower than the non-impact fatigue strength, except for a few cases. In some cases, the impact-fatigue limit is not clearly defined. The impact-fatigue loading gives strength values on the non-conservative side when compared to the values obtained in non-impact fatigue tests. However, the impact fatigue of materials remains less investigated, and a systematic theory and a sound database have not been established for machine parts design and materials selection. This is mainly due to the difficulties associated with impact-fatigue experiments and the complexity of impact-fatigue test results. The impact-fatigue behavior obtained by different authors (Johnson, 1998, 2004; Chatani et al., 2001; Yu et al., 1999; Zhang et al., 1999;

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Table 1 – Properties of acrylic sheet used for the tests

Relative density	1.19
Rockwell hardness	101
Tensile strength	70 MPa
Elongation at break	4%
Flexural strength	107 MPa
Flexural modulus	3030 MPa
Vicat softening point	>105 °C
Co. of thermal expansion	7.8×10^{-5} K^{-1}

He and Zhang, 1998; Yoshimura et al., 1998; Kim et al., 1997; Kobayashi et al., 1997; Shul'ginov and Matveyev, 1997; Yang and Zhang, 1996; Yang et al., 1995, 1996; Miimoni et al., 1996; Pingsheng and Huijiu, 1994; Pingsheng et al., 1994; Jang et al., 1992; Perrin, 1990; Tanaka et al., 1989; Takeyama and Iijima, 1988; Pont, 1988; Dhar, 1988; Radhakrishnan and Prasad, 1974) presents typical fatigue-fracture characteristics. The experimental results of the impact fatigue of materials are usually expressed by the impact energy and impact-fatigue life curve (S–N curve).

The impact studies on acrylic type PMMA sheet materials have been limited to single impact and a full S–N type curve with an endurance limit has not been demonstrated so far. A multi-impacts/impact fatigue study has, therefore, been designed to assess the behavior of these type of materials under repeated impacts are to demonstrate the existence of a fatigue curve with an endurance limit. Effects of different type of notches and loading conditions on multi-impact behavior are also examined.

2. Experimental

2.1. Material

The material used in the present investigation was a hard transparent and clear acrylic type PMMA sheet. This type of sheet materials are now widely used in the workshop because it can be used to make precision engineering components for both domestic and industrial products. Typical applications include signs, glazing, safety screening, roof lighting, furniture, lighting fittings and a great many industrial parts for the medical and chemical industries. This type acrylic sheet is manufactured in two forms; cell cast and extruded sheet and available in a wide range of thickness and colors, including blocks, and surface patterns. In our all experiments extruded clear acrylic sheets (properties are listed in Table 1) are used. Authors feel worth to mention that the basic purpose of the present work is to study the mechanical behavior of these materials to multi-impacts without going detail about its chemical composition.

2.2. Test equipment

A special swinging pendulum type impact-fatigue tester (Resil Impactor™) is used (Fig. 1) for all the experiments. It consists of a pendulum hammer arm (R) with an instrumented striker (I) attached at one end. Other end of the hammer arm is connected to the horizontal shaft of the reducing motor (M), which is controlled by the pneumatic system (P) and compressed air

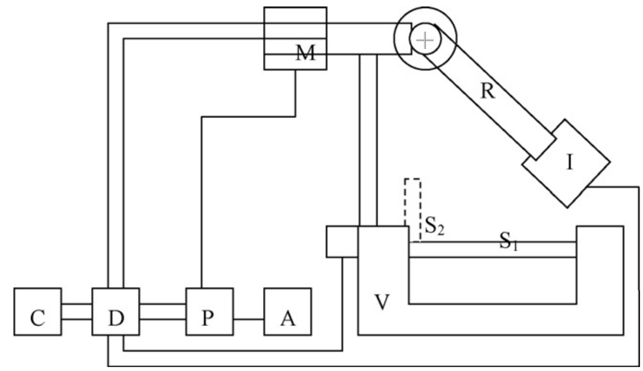

Fig. 1 – Schematic diagram of repeated impact fatigue apparatus.

is supplied by an air compressor (A) attached to the system. The pneumatic system consists of pneumatic actuators for hammer release and braking, the pneumatic distributors and solenoid valves controlling the actuators, the reducer motor for raising and angular positioning of the hammer, the encoder for measuring the drop and rise angle of the hammer and the electronic circuit board with microprocessor for function control and calculation of the test results. The impactor has an instrumented hammer (I) for Izod type test condition and an instrumented vice (V) for tensile type test condition, which are connected to a data acquisition system (D), connected to a PC (P), permits display of the test results in graphic format. The D8EXTWIN™ program is able to control and operate the movements of the apparatus through the PC. The multi-impactor is made of a robust steel structure, on which the components intended for conduction of the test are mounted. In the Izod type test condition (Fig. 2(a)), the specimen (S_2) is supported as an embedded beam and is broken by a single or multiple oscillation of the pendulum at a fixed distance from the specimen clamp and from the center line of the impact. In this case the striker is equipped with strain-gauge type sensor, which is connected to the analog input connector for strain-gauge sensor of the data acquisition system (D). In the tensile type test condition (Fig. 2(b)), the two ends of the specimen (S_1) are supported between a traction terminal (movable) and a clamping bracket and is broken by a single or multiple oscillation of the pendulum on the traction end. In this case the vice is equipped with piezo-electric type sensor, which is connected to the analog input connector for piezo sensor of the data acquisition system (D). The measuring method is based on determining the amount of energy, expressed in Joules, needed to break the specimen under specified conditions, such as: location of the specimen, shape of the notch and speed of impact of the hammer on the specimen. As the maximum potential energy of the pendulum is known, and is in relation to the weight of the hammer used and the drop height, the latter in turn being in relation to the starting angle, it results that the energy absorbed by the specimen in order to break it can be determined by measuring the hammer rise angle after impact.

There are also other parameters that affect this value, such as for example vibrations of the arm and its structure, friction between the various moving members, aerodynamic friction, etc. In order to make the measurements repeatable, these dis-