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Influence of notch on the elastic–plastic response of clamped beams subjected to low velocity impact

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ABSTRACT

In the present paper, experimental and numerical results on deformation and failure of clamped mild steel beams with and without notches subjected to low velocity impact are reported. Three sets of mild steel beams are used in experiments: (i) Beams without notch (ii) beams with 3.0 mm wide rectangular notch and (iii) beams with 0.35 mm wide rectangular notch. The response of the beam is studied in terms of maximum permanent deflection and strain history during contact period. High-speed digital camera was used to capture the impact phenomena of beam specimens. The effect of notch depth, notch width and impact location on the beam response is studied. The presence of notch in beams increases the permanent deflections, and increases the chances of initial tearing failure at the notch location. It is observed from experiments that, the extent of notch influence on dynamic response depends on notch depth and location. In the notched beam, the crack started at the notch corner and extended upwards resulting in failure. The numerical simulations of the experimental impact tests were carried out using the commercial finite element software (ANSYS) and good agreement between numerical and experimental permanent deflection values was observed. The instantaneous distributions of curvature profiles of beam computed numerically are presented for both notched and unnotched beams.

1. Introduction

Menkes and Opat [1] have reported the dynamic plastic response of aluminium beams subjected to impulsive loading. Based on their results, authors have identified three failure modes: large inelastic deformations (mode I failure), tensile tearing (mode II failure) and shear failure (mode III failure) at supports. Kumar and Petroski [2] developed a rigid perfectly plastic model to study the effect of a central crack on the plastic response of a beam subjected to central transverse impact load. Authors have reported that locations of plastic hinges and the amount of permanent deformation associated with a central crack are dependent on the size of the crack. In an another experimental study, Woodward and Baxter [3] studied the response of continuous and notched free–free beams to a transverse impact load applied at one end and reported angle of bend and rotation of one part of the beam with respect to the other part. From the experimental studies authors have shown that the response of beams is greatly influenced by position and depth of notches and angle of bend of the notched beam is insensitive to notch depth. It is observed by authors that, due to the presence of notch the beam will undergo localized plastic deformation. Liu and Jones [4] and Yu and Jones [5] studied experimentally the failure and deformation characteristics of clamped steel and aluminium beams struck transversely by impact loads. Two types of failure were observed in experiments: tensile tearing failure and shear failure for sufficiently large impact energy. It was also observed that, energy absorbing capacity of beam decreased when it was struck near the support point. They have quantified the influence of material strain rate effect on the response. Liu and Jones [6] examined theoretically the influence of shear force and membrane force on the deflection of (rigid perfectly plastic model) clamped beams struck by an impactor. Authors observed that transverse shear force might dominate the response when the beam is impacted near the support and membrane force plays an important role if the deformation is larger than beam thickness. Marur [7] studied the dynamic response of pre-cracked specimens using conventional beam and finite element method. The numerical results are compared with the experimental results of instrumented Charpy test conducted on aluminium and polymeric material. Numerical simulation of clamped mild steel beam subjected to transverse impact load was carried by Yu and Jones [8] by

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Nomenclature

b	Width of the beam
d_n	Depth of the notch
E	Young's modulus
E_T	Tangent modulus
h	Thickness of the beam
L	Half length of the beam
l_{il}	Distance of impact point from the left support
m	Mass of the impactor
μ	Poisson's ratio
V_0	Velocity of the impactor at the time of contact
W_v	Maximum permanent transverse deflection
λ	Dimensionless dynamic (impact) energy parameter, $mV_0^2 l_{il}/2bh^3\sigma_y$
σ_u	Ultimate stress
σ_y	Yield stress
ρ	Mass density of beam

using finite element code ABAQUS. Authors compared the numerical results with the experimental results obtained earlier by Yu and Jones [5]. Eight-noded isoparametric plane stress elements were used to model the beam and four noded bilinear plane stress elements were used to discretize striker. True stress–strain relationships were used in the analysis together with material nonlinearity. The striker was simplified and reduced to a cube with large density but having the same mass as used in the experiment. The detailed information of the beam response during the impact event was obtained and various failure criteria were examined and discussed using the experimental and numerical results. Yu and Chen [9] examined the shear failure (mode III) of impulsively loaded clamped beams. Authors evaluated the effect of interaction between shear force, bending moment and weakening of sliding sections on the failure process. They suggested modifications to elementary failure criterion by incorporating the sliding section weakening effect. In a subsequent paper, Yu and Chen [10] have surveyed the failure modes and failure criteria of structural members subjected to intense dynamic loads. Authors incorporated J-integral criterion into the global structural failure description to predict failure of structural members with macroimperfections. The response and failure of beams made from medium carbon steel alloy subjected to impact loading were studied experimentally by Li and Jones [11]. Response and failure features were obtained for impact velocities between 30 and 110 m/s and they observed failure mode transition between a ductile tensile rupture failure and a shear banding failure. Chen and Yu [12] investigated experimentally the failure behavior of clamped aluminium beams with one and two pre-notches to projectile striking. They showed that, with the presence of pre-notches, the beam's dynamic response pattern would change from a global ductile plastic deformation to a local strength failure. Further, the effect of pre-notch was found to be strongly location dependent and surface dependent. Also, authors observed that, due to notches, the beams failed by inelastic deformation.

It is observed from the literature, that the presence of notches in beams changes contact period, strain profile, localized plastic deformation, and failure mode of the beam. Thus, it is important to understand the influence of notches on the dynamic response of beams subjected to impact loading. However, very few experimental results are available on this important problem. In the present investigation, the impact response of clamped mild steel beams subjected to low velocity transverse impact at the mid span and at the quarter span is studied for two different notch depths (i.e. for 1/3 and 1/2; the depth of the beam) and two different notch widths experimentally. The tests were conducted to study, (i) the effect of notch location, notch width and notch depth and (ii) the effect of increasing impact energy on the response of clamped beams subjected to mid span and quarter span impact. Experiments are numerically simulated using the finite element code ANSYS. Experimental results show that the notch width does not have significant effect on the dynamic response of beam as compared to notch depth and notch location.

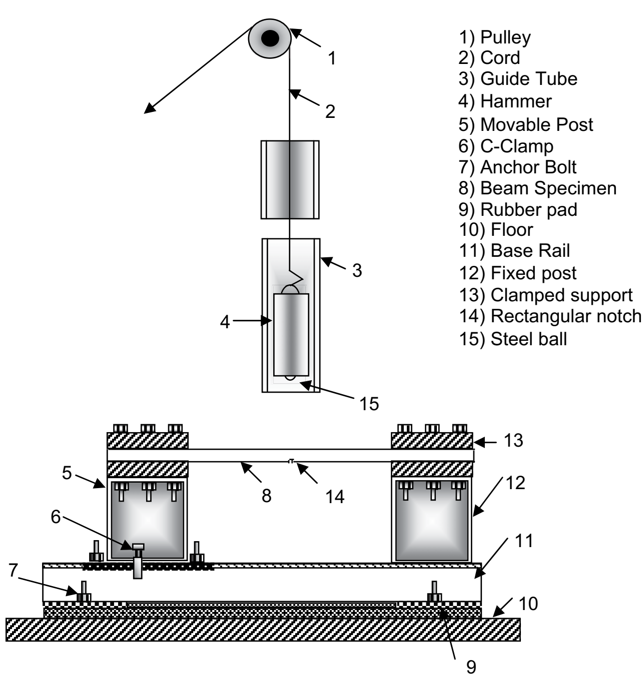

Fig. 1. Schematic view of the drop hammer experimental setup.

2. Experimental details

2.1. Drop hammer setup

The in-house built drop hammer experimental setup used in the present study to conduct tests on the mild steel clamped beams is shown in Fig. 1. The test setup consists of a base rail, which is fixed firmly to the ground using four anchor bolts (two each on either side). Between the floor and the base rail a rubber pad is provided to damp out vibrations occurring during impact. Two vertical posts are attached to the base rail as shown in Fig. 1. One of them is welded to the base rail and the other is a movable post. The movable post will be fixed to the base rail using a C-clamp and four bolts as per the requirement. Both posts are of the same height, over which a thick plate is welded. The surfaces of these plates are ground smooth and leveled. The test specimens are kept over these plates. Another plate of the same thickness is placed over the test specimen. The clamped boundary condition is achieved by firmly fixing the beam, between the top plate and the bottom plate using bolts. A seam less guide tube is fixed to a support such that it is perpendicular to the axis of the test specimen. A steel impact hammer, having a mass 5 kg/10 kg is suspended through the guide tube using a chord, which passes over a frictionless pulley. Hammer can be dropped from different heights and can achieve a maximum velocity of 5.5 m/s. A steel ball having diameter 9 mm is welded to the hammer at the centre of bottom surface (impact point). The test