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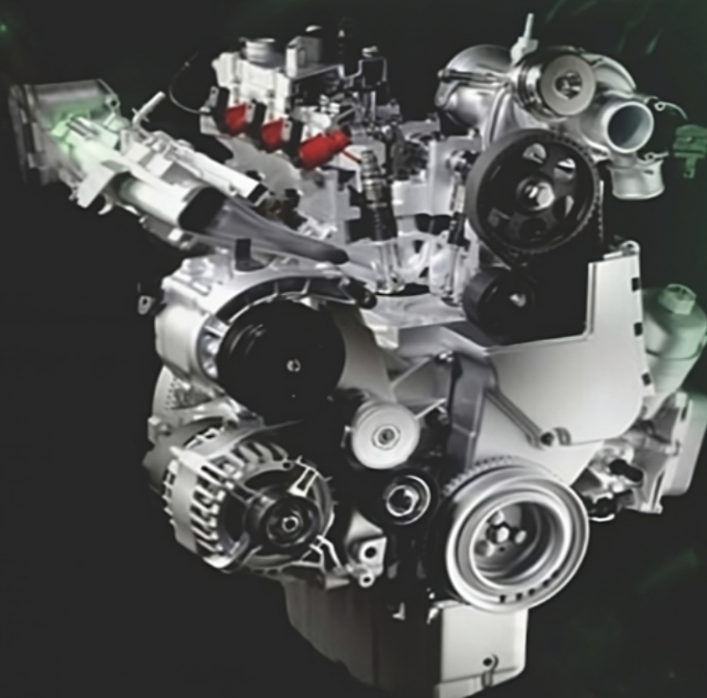

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NUMERICAL EVALUATION OF CHARPY IMPACT TEST PERFORMANCE FOR ALUMINIUM ALLOY

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ABSTRACT

Proper interpretation of the material behaviour is of utmost importance, especially under dynamic loading, while designing a structure. The main objective of the current study is to estimate the impact strength of Aluminum alloy by Charpy test numerically. It is considered to be a cost-effective test which is extensively utilized to estimate the energy absorbed during fracture under impact loading by a notched specimen. However, the experimental measurement of the same may be cumbersome and time-consuming. Thus, the current study imparted the simulation-based approach to understand the toughness behaviour of the alloy under a high strain rate at room temperature. The three-dimensional finite element simulation analysis considered the effect of major parameters such as striker notch radius and striker velocities on energy absorbed by the material at a high strain rate in room temperature conditions. The simulation utilized the Johnson-Cook (J-C) approach to model the fracture behavior under the impact loading conditions. The J-C model parameters were taken from an *independent literature. This paper may serve as a basis to measure the fracture toughness of metals.*

Keywords: Charpy impact test, Aluminium alloy, Johnson-Cook Fracture

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1. Introduction

Lightweight metals and alloys have a wide application in aerospace, aviation, automobile, and naval industries etc. Among the potential lightweight materials, aluminium has drawn special attention of researchers due to their inherent properties such as low density, better thermal conductivity, good fracture resistance, and good corrosion resistance with an appreciable tensile strength at room temperature [1]**.** The study of fracture resistance characteristics of aluminium alloys is important during both static and dynamic loading conditions. Normally, materials show even behaviour under static loading conditions, on the other hand, under dynamic loading when subjected to a high strain rate the mechanical behaviour of materials is largely affected [2]. Due to this, the study of the mechanical behaviour of materials under dynamic loading conditions is necessary. It is well known that impact testing is one of the accurate and precise experiments that help in recognizing the mechanical behaviour of the material under high strain rate conditions. The high strain rate analysis mainly by numerical method during impact testing incorporates the effect of inertia and strain rate sensitivity simultaneously[3]by running thematerial model is used in dynamic explicit mode. The Johnson-Cook (J-C) material model and J-C damage model is used to capture the hardening, strain rate, and temperature effects accurately during high-strain processes such as the metal forming and machining processes [4]**.** The Charpy impact analysis has been predicted as a reliable and cheaper testing technology in which the Charpy V- notch specimen breaks by striking the striker at a high strain rate. This evaluated the amount of energy absorbed by the material under dynamic loading conditions [5]**.**

Many efforts have been made in the field of impact testing analysis by Charpy's test to understand the behaviour of materials under dynamic loading conditions both experimentally [6-8]and numerically [8]**.**However experimental investigations are time-consuming and tedious. Thus Madhusudhan et al. [8]has investigated the modelling and simulation of the Charpy Impact test of maraging steel 300 using a finite element package in an explicit solver in ABAQUS. The impact test simulation is completed at different pendulum velocities i.e., 5 m/s, 6 m/s, 7 m/s, and 9 m/s using the J-C material and damage model. It is observed that the energy absorbed by the upper shelf region increased with the increase of impactor velocity. While the impact energy of the lower shelf region decreased with the increase of impactor velocities**.** Xu et al.[9] studied the effect of temperature and strain rate at a range of values i.e., 288 K to 873 K and 0.001 s^{-1} to 4500 s^{-1} respectively on the thermal softening behaviour of armour steel 603. The softening behaviour of the material has increased with the increase in temperature and decrease in strain rate value. Gaith & Khan [10]explored impact toughness analysis for normalized steel and aluminium via Charpy impact specimen under the 3D Non-linear finite element modelling technique. The sample was designed according to ASTM E-23 with U and V-type notches at the centre. The impact energy of the U-shape notch has been observed more as compared to the V- shape notch due to less effect of stress concentration at the notched end. Gonalez et al.[11]focused their research work on fracture toughness estimation of pre-fatigue AISI4140 T-steel and A6061-T6 aluminium materials, using Split-Hopkinson bar apparatus set-up. The AISI4140 T-steel showed a higher fracture toughness compared to the A6061-T6 aluminium. The numerical simulation results showed the same peak value of fracture toughness as they had observed in the experiment**.**Gaith[12]investigated the impact of toughness behaviour on normalized carbon steel at a range of temperatures from (-600 ^{0}C to +600 ^{0}C) with the help of experimental and numerical analysis. The experimental, as well as numerical results, showed a satisfactory response. It is observed that the DBTT behaviour for the normalized carbon steel was 0^{0}C [5]**.** The ductile to brittle transition (DBTT) failure for welded zones of a porous plastic solid was analysed by Tvergard andNeedleman[13]using dynamic explicit FE analysis. It is observed that a strong dependency on stress tri-axiality over the DBTT temperature.

In the present study, finite element modelling was developed using dynamic explicit mode in ABAQUS software which aids in improving the accuracy and reducing the cost of toughness measurement. The material hardening and damage behaviour was simulated using the J-C material model and damage model. This material model incorporates the material hardening, and strain rate effects simultaneously.The objective of the present research work is a numerical modelling study of the toughness behaviour of AA6061 aluminium alloy under dynamic loading using a FEM dynamic explicit solver. The parameters required are adopted from independent literature[6]**.**

2 Numerical Modelling by Finite Element Analysis

The experimental measurement to measure the energy stored by a variety of materials under both static and dynamic loading conditions are abundant and being increasingly implemented. However, numerical modelling and estimation of fracture toughness serve as beneficial by decreasing the material loss, time, and energy. With proper approximation and boundary conditions, a numerical model may remove the cumbersome associated with experimental investigation. Thus, the constitution of an accurate material model for the estimation of fracture toughness can reliably describe the mechanical behaviour and improve the in-service performance of the material. The Charpy impact test is performed to measure the material model behaviour numerically to predict the energy absorbed by the specimen under high strain loading conditions. The accuracy of the results depends on the design of the striker. To understand the effect of notch radius over the energy absorbed by the specimen two different shapes of the striker are incorporated (0.2 mm and 0.8 mm) to model the Charpy impact test.

2.1 Theoretical Background

2.1a Johnson-Cook Material Model

I.G. R. Johnson – W. H. Cook [3] presented a constitutive model and damage model and data for materials subjected to large high strain rates and high temperatures. This model is used to define the hardening behaviour of the damage for a ductile material. The model for the Von-misses flow stress, σ, is expressed as:

$$\sigma_{eq} = \{A + B * \varepsilon_p\}\left\{1 + Cln\frac{{\varepsilon_p}^*}{{\varepsilon_p}^0}\right\} \qquad (\mathbf{1})$$

The first term in the above expression contains the effect of elastic-plastic deformation behaviour i.e., power law or hardening law, the second term encounters the deformation behaviour or strain rate behaviour under viscous-plastic condition and the third term represents the temperature softening behaviour.

Where A(MPa) is the elastic limit or the yield stress, B(MPa) is the strain hardening parameter, n is the exponent of the strain hardening, and C is the strain-rate sensitivity index. ε_p(Accumulated plastic strain) signifies the accumulated plastic strain inside the material, ${\varepsilon_p}^*$ the actual reference strain rate and ${\varepsilon_p}^0$ denotes the plastic strain rate at a reference condition.

2.1bJohnson-Cook Fracture/Damage Model

The Johnson-cook (J-C) [3] damage model is implemented to define the damage characteristics of material during impact loading conditions. The expression for fracture or damage strain is as follows. The first term considers the effect of stress tri-axiality ratio on the fracture strain; the effect of strain rate is accounted for by the second term in the fracture strain equation and the third term accommodates the effects of temperature in the material fracture strain.

$$\epsilon_f = \{D_1 + D_2\, expD_3\sigma^*\}\{1 + D_4 log(\dot{\varepsilon}^*)\} \qquad \textbf{(2)}$$

Where $\epsilon_f$are the strain to a fracture or fracture strain, under the current condition of strain rate, temperature, pressure, and equivalent stress. Fracture is then allowed to occur when D is equal to one. D_1 to D_4 are the material constants. The$\sigma^* = \frac{\sigma_m}{\sigma_{eq}}$; is named as stress tri-axiality which is the ratio of mean stress or hydrostatic stress to the von-mises equivalent stress.

2.1cJohnson-Cook material model and damage model process parameter

The Johnson-Cook (J-C) material model was used to incorporate the effect of high strain rate, and deformation behaviour during the Charpy impact test simulation. In addition, this describes the hardening behaviour of material while deformation.

Table **1Johnson-Cook** material model and damage model parameters [6]. shows the J-C material and damage model parameters for the Charpy specimen whereas the mild steel properties are given to the striker.

Table 1 Johnson-Cook material model and damage model parameters [6].

Material model parameters				
A	B	C	n	m
324MPa	114MPa	0.002	0.42	ignored
Damage model parameters				
D1	D2	D3	D4	D5
-0.77	1.45	0.47	0	ignored

2.2 Geometrical model and material properties

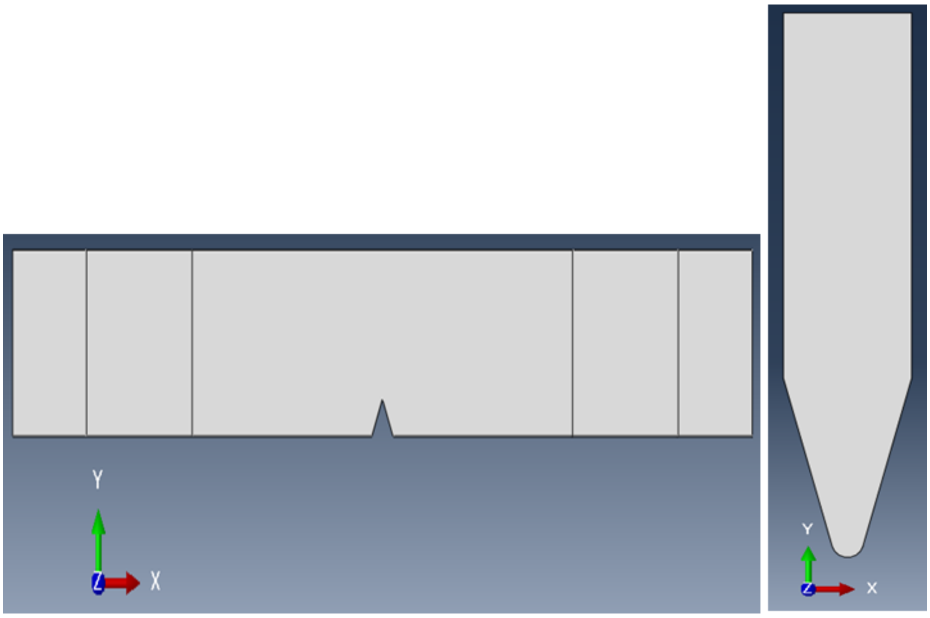

Fig. 1 Geometrical model of Charpy impact specimen and striker.

Error! Reference source not found. Shows the geometry of the striker and standard Charpy V-notch impact toughness testing specimen. According to ASTM: E23, the standard dimension of the Charpy specimen of Al-6061 is 56 x 10 x 10 mm^3 with V-notch having a notch depth of 2 mm and 45^0 interior angles. This V-notch presented in the Charpy specimen incorporates the effect of discontinuities, cracks and other flaws that were presented in the material. The striker, made up of mild steel, with two different notch radius of 0.2 mm, and 0.8 mm is used to impart the impact loading to the Charpy specimen while the Charpy impact test simulation.

Table **2** shows the general physical properties of AA6061 and mild steel. In this study, the striker is made up of mild steel and the Charpy V-notch specimen was made up of AA6061 aluminium alloy. The contacting surfaces of the striker and the Charpy specimen are defined as master and slave surfaces respectively. The strength of the master surface is more compared to the slave surface.

Table 2 General physical properties of Charpy V-notch specimen and anvil [6].

Properties	Charpy-specimen	Striker
Material	Al-6061	Mild steel
Density (Kg/m^3)	2700	7800
Young Modulus (GPa)	70	200
Poisson ratio	0.33	0.25

2.3 Assembly and meshing

There are mainly two kinds of surfaces created for the analysis. The surface which has a higher strength is known as the master surface whereas the lower-strength body is assumed as the slave surface. First, the striker, made up of mild steel, is defined as a master surface. While the Charpy impact specimen is defined as a slave surface, Second. Succeeding the property module, these two individual surfaces have been assembled in the assembly module. The mode of contact between the master surface and slave surfaces is surface-to-surface dynamic explicit.

The mesh control parameter is used to define the mesh size of the two regions i.e., finer size region and coarse size mesh on the Charpy specimen as shown in **Error! Reference source not found.**. The fine mesh is adopted near the regions of the v-notch whereas the regions away from the v-notch and towards the outer surface are coarsely meshed. The C3D8R structural element is used for the meshing of the Charpy specimen and striker. The Charpy specimen is discretized in a total of 661450 linear hexahedral elements with 689010 nodes. The local seed size of 0.2 mm near the circular surface and 0.8 mm outer to the circular nose surface is given to the striker. Similarly, the seed size at the regions near to crack tip is 0.2 mm and the seed size beyond the crack tip is 0.8 mm. To visualize the crack initiation and propagation phenomenon in the Charpy specimen, element deletion options has adopted. The use of hourglass control helped in increasing the mesh convergence rate resulting smooth flow of cracks, during high strain rate dynamic loading, without defining the extra constraint to the elements.

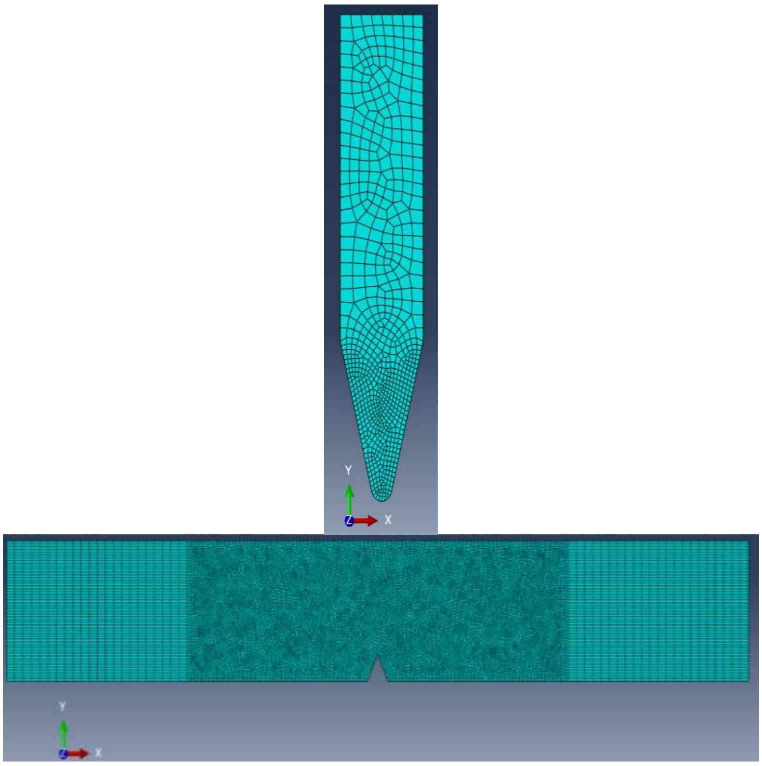

Fig. 2 Meshing of Charpy specimen, anvil and rollers and its meshing

2.4 Boundary condition and process parameters

This study used the dynamic explicit solver to solve the stiffness matrix, which continuously changes during crack propagation. Two types of boundary conditions have been imposed on the model to prepare the simulation setup for the Charpy impact test. First, the displacement/ rotation type condition i.e., as $U_x = 0$ and $U_z = 0$ that applied to the striker to restrict their motion in the x-axis and z-axis directions. This allowed the free movement of the striker in the XZ plane to impart the load on the Charpy specimen. Second, the displacement/rotation type is applied to the Charpy specimen to provide the simply supported constraints which are defined as $U_{(x\text{-translation})} = U_{(z\text{-translation})} = U_{(x\ y\ \text{rotation})} = U_{(y\ z\text{- rotation})} = 0$. The striker is subjected to varying velocities to impart the different ranges of strain in the Charpy specimen. This simulation study has used the total analysis time of 0.002 seconds whereas the frequency of output at each incrementation is $1\text{x}10^{-5}$ seconds.

3 Result and discussion

There are many factors affecting the correctness and dispersion of impact energy absorbed by the material such as the states of the specimen (size, notch type and depth), the states of the impact test machine (stiffness, striker radius, base span etc.), the test conditions (impact speed, temperature, etc. This simulation analysis considers the effect of major parameters such as striker notch radius and striker velocities on energy absorbed by the material at a high strain rate in room temperature conditions. Fig. 1 Fractured Charpy specimen after hitting the striker at a velocity of 4.5 m/s. shows the fractured Charpy V-notch specimen with 0.002 sec analysis time.

3.1 Effect of striker velocity on Von-Mises's stress in Charpy specimen

The maximum and minimum values of von mises stresses, subjected to the structural component during the crack propagation with a radius of 0.8 mm striker, are shown in Fig. 2 Von-mises stresses and corresponding crack openings of Charpy specimen at striker

velocities of (a) 2.0 m/s, (b) 2.5 m/s, (c) 3.0m/s, and (d) 3.5 m/s with 0.8 mm notch radius. The maximum value of von-mises stresses has increased with the increase of velocities from 2.0 m/s to 4.0 m/s respectively. The peak value of von-mises stress varies between 346 MPa and 425 MPa with velocities of 2.0 m/s and 4.0 m/s respectively. The crack mouth opening from the 2.0 m/s specimen extended with an increase in the striker velocities. The increase in velocity has caused rapid crack propagation due to the high strain rate associated with the material. The material starts absorbing energy once the striker makes the contact with the testing specimen and reached the maximum value and a sudden fall in strain energy due to the breakage of the specimen in two parts.

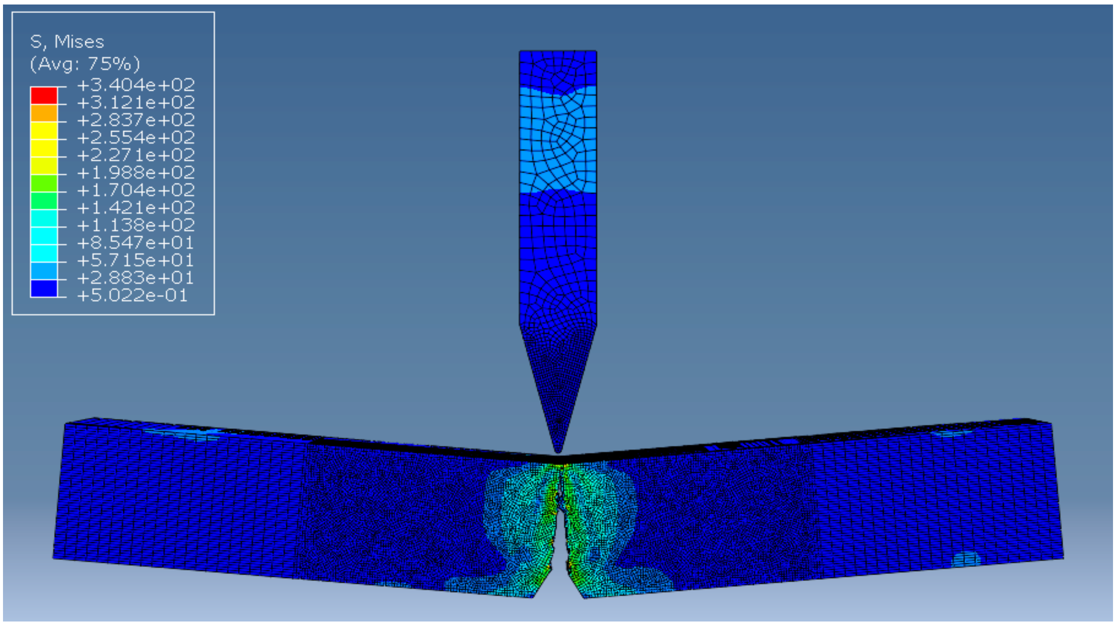

Fig. 1 Fractured Charpy specimen after hitting the striker at a velocity of 4.5 m/s.

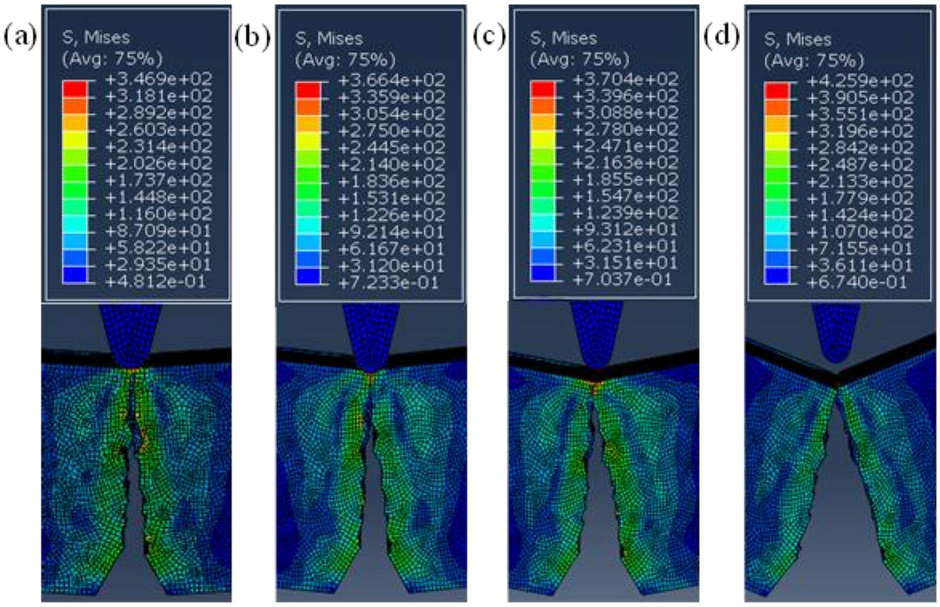

Fig. 2 Von-mises stresses and corresponding crack openings of Charpy specimen at striker

velocities of (a) 2.0 m/s, (b) 2.5 m/s, (c) 3.0m/s, and (d) 3.5 m/s with 0.8 mm notch radius.

3.2 Effect of striker velocities on strain energy absorbed

The variation of strain energy absorbed with time at different striker velocities, such as 2.0 m/s (Black), 2.5 m/s (Red), 3.0 m/s (Blue), 5 m/s (Pink), and 4.0 m/s (Green) using 0.8 mm striker notch radius, are shown in Fig. 3 Strain energy absorbed by the Al-6061 Charpy specimen with striker notch radius of (a) 0.2 mm and (b) 0.8 mm radius respectively.. It is observed that the strain energy absorbed by the Charpy V-notch specimen has increased with a decrease in striker velocities and vice versa, due to the strain rate which is imparted by the striker to the specimen. The peak value of strain energy has decreased on a further increment of velocity from 2.0 m/s to the maximum velocity of 4.0 m/s. The increase in striker velocity has caused a quicker crack propagation rate in the specimen due to the high strain rate. This might be the potential cause of cleavage fracture in the material.

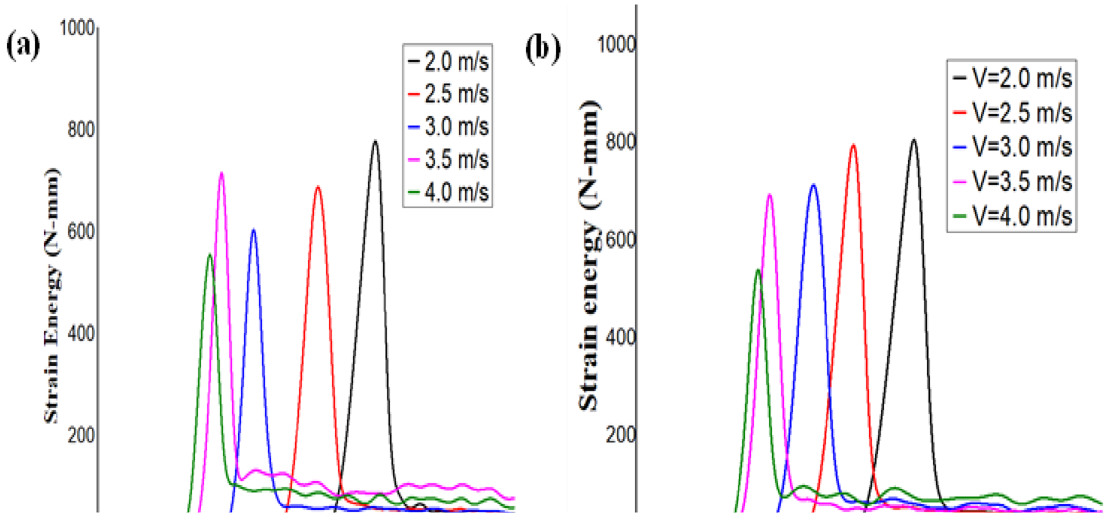

Fig. 3 Strain energy absorbed by the Al-6061 Charpy specimen with striker notch radius of (a) 0.2 mm and (b) 0.8 mm radius respectively.

Fig. 5 Strain energy absorbed by the Al-6061 Charpy specimen with striker notch radius of (a) 0.2 mm and (b) 0.8 mm radius respectively

3.3. Effect of striker velocities on internal energy absorbed

Error! Reference source not found.reflects the variation of internal energy absorbed with time at different striker velocities, such as 2.0 m/s (Black), 2.5 m/s (Red), 3.0 m/s (Blue), 5 m/s (Pink), and 4.0 m/s (Green) using 0.8 mm and 0.2 mm striker notch radius respectively. When the striker, hit the Charpy specimen, the kinetic energy of the striker is converted into potential energy stored by the specimen. It is observed that the curve of 5.0 m/s (Black) shifted towards the right side with an increase in striker velocities. The increase in velocities enhances the early failure of the component. However, the internal energy capacity of the specimen has increased further with an increase in velocities and finally quicker failure.

3.4. Effect of striker radius

It is observed that the difference in internal energy absorbed at each velocity by the Charpy specimen with a striker radius of 0.2 mm is more as compared to the 0.8 mm striker radius due to the lesser contact area between Charpy specimen and striker shown in **Error! Reference source not found.** The decrease in the radius of the striker from 0.8 mm to 0.2 mm caused the increase in stress value due to the higher effect of stress concentration.

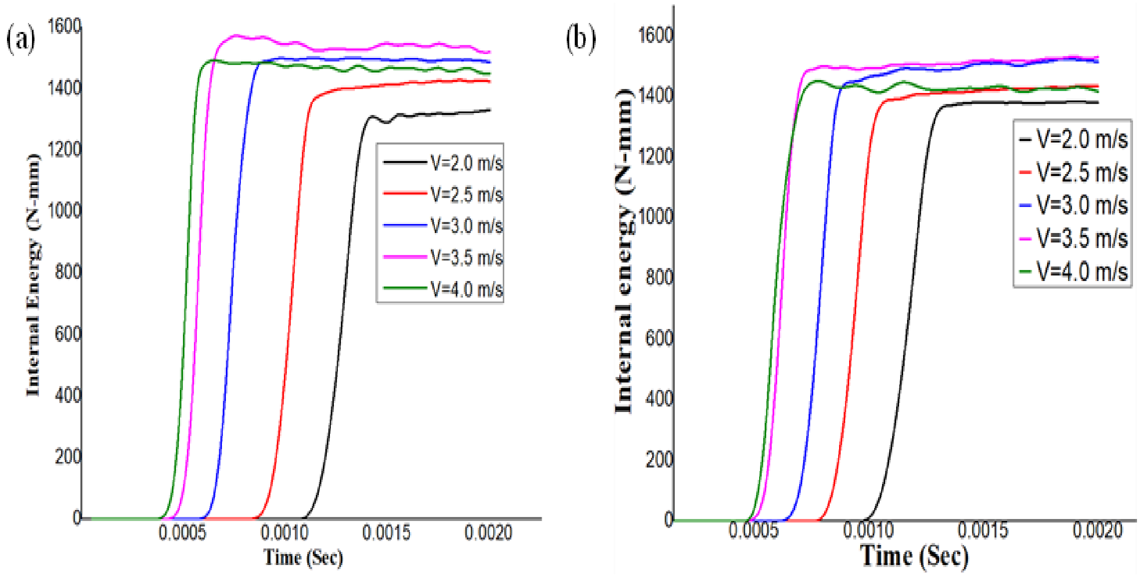

Fig. 6 Internal energy absorbed by the Al-6061 Charpy specimen with striker radius of (a) 0.2 mm, and (b) 0.8 mm respectively

4 Conclusions

1) This study imparted the simulation-based approach for a better understanding of the toughness behaviour of the Al-6061 aluminium alloys under high strain rate conditions in a room temperature environment.
2) This simulation methodology utilised the Johnson-Cook (J-C) approach to model the material behaviour and fracture behaviour under the impact loading conditions. The selection of Johnsen-Cook parameters controls the accuracy of the model.
3) The dynamic explicit solver has solved the stiffness matrix that was continuously changing during the crack propagation. The strain energy of the specimen first increased then decreased due to the crack initiation and propagation with the increase of velocities. The

use of hourglass control helped in increasing the mesh convergence rate resulting smooth flow of cracks, during high strain rate dynamic loading conditions.

4) The change in striker notch radius has predicted little change in increase in strain energy and decrease in internal energy of material with the increase of striker velocities. However, the sudden jump in strain energy is observed at 2.5 m/s striker speed with 0.2 mm as compared to 0.8 mm striker notch radius.
5) This study will be helping in predicting the fracture toughness behaviour of the Al-6061 alloys under both elevated and cryogenic temperatures in future.

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Conflict of interest

The author declares no conflict of interest.

References:

[1] HatchEJohn 1984 Aluminium: Properties and Physical Metallurgy, ASM International; Subsequent edition.

[2] DavisR. Joseph 1993 Aluminum and aluminum alloys. ASM international.

[3] Behrens Arno Bernd, Lippold Lennard and Knigge Julian 2013 Investigations of the shear behaviour of aluminium alloys. Prod. Eng. Res. Devel. 7, 319–328.

[4] Xu Honghe, Zhang Yue, Peng Ruitao, Zhu Linwei and LuYan 2021 Simulation and experimental study on the strength of Al7075-T6 clinched joint. Eng Fail Anal 129:105735.

[5] Banerjee A, Dhar S, Acharyya S, Datta D, and Nayak N 2015 Determination of Johnson cook material and failure model constants and numerical modelling of Charpy impact test of armour steel. Mater Sci Eng A 640:200–209.

[6] Alhussein A, Capelle J, Gilgert J, Tidu A, Hariri S and Azari Z 2013 Static, dynamic and fatigue characteristics of the pipeline API 5L X52 steel after sandblasting. Eng Fail Anal 27:1–15.

[7] Yildiz RA 2022 Evaluation of fracture toughness and Charpy V-notch test correlationsforselectedAlalloys. EurMechSci6:1–8.

[8] Mathur KK, Needleman A, Tvergaard V 19943D analysis of failure modes in the Charpy impact test. Model Simul Mater Sci Eng 2:617–635.

[9] Madhusudhan D, Chand S, Ganesh S, Saibhargavi U 2018 Modelling and simulation of Charpy impact test of maraging steel 300 using Abaqus. IOP Conf Ser Mater Sci Eng 330.

[10] Xu J, Song W, Cheng W, Chu L, Gao H, Li P and Berto F 2020 Modelling of fracture toughness of x80 pipeline steels in dtb transition region involving the effect of temperature and crack growth. Metals (Basel) 10.

[11] Ghaith Fadi and Khan Fahad 2013 Threedimensional nonlinear finite element modelling of charpy impact test.Int J Mech Eng Technol (IJMET), ISSN 0976 – 6340(Print), ISSN 0976 – 6359(Online) Vol 4, Issue 4:377–386

[12] Rubio-González C, Gallardo-González JA, Mesmacque G, Sanchez-Santana U 2008 Dynamic fracture toughness of pre-fatigued materials. Int J Fatigue 30:1056–1064.

[13] Ghaith FA 2010 Nonlinear finite element modelling of charpy impact test. Adv Mater Res 83–86:182–189.

[14] Tvergaard V, Needleman A 2000 Analysis of the Charpy V-notch test for welds. Eng Fract Mech 65:627–643.

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