Evaluation of Crashworthiness for SAE Materials under Ductile to Brittle Transition Temperature (DBTT)

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Abstract- The concept of crashworthy coaches came into existence after a crash. This demands, avoid vehicle deformation of other/central parts. For this, the behaviour of plastic deformation of the material is necessary to be known. So, these results are required to study the crashworthy behaviour of the structure. In this research, Comparative study has been taken on the automotive materials of SAE 1026, SAE 4140, SAE 5120 and SAE8620. This paper presents the results of fracture toughness, impact energy and stress required for crack propagation from Charpy v-notch impact test and tensile test. The mechanical behaviour of SAE 1026, SAE 4140, SAE 5120 and SAE 8620 are important to describe response during actual loading condition properties used in the crash analysis of the component. The Charpy impact test was conducted at temperature ranging from room temperature 24°C, 0°C, -20°C, -40°C, -60°C. Specimens oriented in T-L direction are tested. The materials SAE 1026, SAE 4140, SAE 5120 and SAE8620 shown that the ductile to brittle transition temperature, based on 19.5 J, 10.5 J, 113 J, 59.5 J, absorbed energy is about 1.2°C, -3°C, -38°C, -10°C respectively.

Keyword-Crashworthiness, Charpy Impact Energy, DBTT, SAE Materials

I. INTRODUCTION

Automotive crashworthiness is the capability of a car structure to provide adequate protection to its passengers from injury in the event of a crash. The trend today in the automotive industry is for crashworthiness to include the ability of the car to withstand minor accidents with little damage. In engineering structures, strength often must be combined with toughness, which indicates the amount of energy absorbed during the deformation and fracture. In order to prevent brittle, i.e. catastrophic failure, the service temperature of the structural component must be higher than the material's ductile to brittle transition temperature [1]. The advantages of Charpy testing are that it is a rapid test method requiring small investment, test specimens are of small size and simpler to machine (Wullaert:, 1970, 1974). The Charpy test, which determines the amount of energy absorbed by a material during fracture, predicts the performance of materials in service condition. It reproduces the ductile to brittle transition of steel in about the same temperature range as it is actually observed in engineering structures. Through Charpy test the important data that can be generated are the absorbed energy, the ductile to brittle transition temperature (DBTT) for 50% cleavage fracture area and lateral contraction at the root of the notch (Pellini:, 1954) to measure ductility transition temperature (for 1% lateral contraction) [2,7]. The Samples were tested on a Charpy impact machine with maximum impact energy of 300 J. For testing above or normal room temperature, samples were held for at least 30 min in an air circulating oven, and for testing below room temperature, in liquid refrigerants for at least 10 min. Then samples transferred to the Charpy impact machine and tested within 5 s. The results are generally representative of CVN impact energy Vs temperature. In the plot, three regions can be identified as the lower shelf, the transition and upper shelf region. The fracture mode in lower shelf is typically brittle such as cleavage while in the upper shelf is ductile with void growth and coalescence [3, 5]. The ductile to brittle transition temperature (DBTT) is a phenomenon which is widely observed in BCC metals and in covalently based materials. Below a critical temperature (DBTT), the materials suddenly lose their ductility [4]. According to ASTM standard E399, fracture toughness testing of metals based on linear-elastic fracture mechanics. In order to compare the energy absorption performance of SAE materials, engineering stress-strain curves and were used. In the transition temperature range, fracture energy and the ductile area has a large scatter. During the impact test, the energy is absorbed mainly by plastic deformation and the elastic energy remains practically constant. The stored elastic energy is the driving force for cleavage crack propagation, which is the limiting process for ductile crack growth [6].

II. SELECTION OF MATERIALS

The aim of this paper is to study crashworthy behaviour of the SAE automotive materials are selected here as SAE1026, SAE4140, SAE5120 and SAE8620 under stated ductile to brittle transition temperature range. First two different specimens have prepared for testing materials under tensile test to study elastic behaviour and Charpy impact test to study fracture behaviour during the temperature range.

A. Chemical composition

The chemical composition of SAE materials as:

TABLE I
Chemical composition of SAE materials

Material	C%	Mn%	Cr%	Ni%	Mo%
SAE1026	0.2	0.5	-	-	-
SAE4140	0.42	0.84	1.01	-	0.22
SAE5120	0.2	1.21	1.03	-	-
SAE8620	0.23	0.81	0.54	0.51	0.18

B. Heat treatment

Here the test specimen is subjected to impact and required maximum toughness. During this test, specimen undergoes through normalizing process. Normalizing consists of heating the material to about 30-50°C above the critical temperature and holding it at that temperature for a short period, which is sufficient ensure formation of homogeneous austenite and then fast cooling in still air [5].

III.TEST SPECIMEN AS PER ASTM

A. Charpy V-Notch Specimen

Table II shows dimensions of full size Charpy v-notch specimen:

TABLE III
Dimensions of Charpy v-notch specimen

Parameter	Total length	Height	Width	Notch angle	Notch root radius
Dimensions(mm)	55	10	10	45°	0.25

B. Tensile test specimen

Table III shows dimensions of ASTM Standard Tensile Test Specimen:

TABLE IIIII
Dimensions of ASTM Standard tensile test specimen

Parameter	Diameter	Gauge length	Grip length	radius of fillet	Length of reduced c/s
Dimensions(mm)	12.5	50	23	10	60

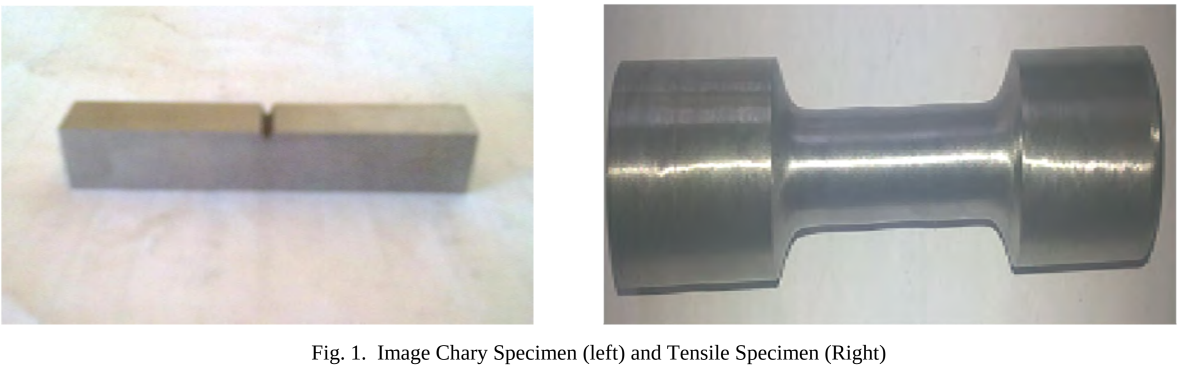

Fig. 1. Image Chary Specimen (left) and Tensile Specimen (Right)

IV. EXPERIMENTAL INVESTIGATION FOLLOWED

A. Tensile Test

Tensile test are useful here to achieve material parameters such as Ultimate Strength (UTS), Yield Strength (YS), % Elongation (% EL), % Area of reduction (% AR) and Young's modulus (E). This test characterizes properties related the mechanical behaviour of materials. Record all properties, which is required.

B. Charpy Impact Test

The Charpy V-notch test usually characterised ductile-to-brittle transition temperature (DBTT). The DBTT value here according to with change in impact energy absorbed by specimen with change in test temperature. In Charpy impact test, DBTT can be evaluated as midpoint temperature value between upper shelf energy and lower shelf energy. In this test, a pair of specimens will be tested at individual temperatures using the mediums as listed in Table IV:

TABLE IVV
Temperature and mediums used for Charpy impact testing

24°C	0°C	-20°C	-40°C	-60°C
Room temperature	Liquid nitrogen	Liquid nitrogen	Liquid nitrogen	Liquid nitrogen

Impact Testing was performed on four specimens at 24°C, 0°C, -20°C, -40°C, and -60°C temperature range. For CVN specimens with test temperatures at 0°C, -20°C, -40°C, and -60°C liquid nitrogen temperature used. After specimen, Charpy Impact test was performed on each specimen to measure absorbed facture toughness energy and plot the ductile to brittle transition temperature curves for each specimen of SAE1026, SAE4140, SAE5120 and SAE8620.

V. RESULT AND DISCUSSION

A. Tensile Test Results

The dimension and material behaviour properties for SAE materials referred in tensile test are formulated in tabular form in Table V.

TABLE V
Tensile Test Parameter

Materials	SAE1026	SAE4140	SAE 5120	SAE 8620
Gauge length	50mm	50 mm	50mm	50mm
Gauge diameter	12.5mm	12.56 mm	12.5mm	12.52mm
Original area	122.72 mm^2	123.89 mm^2	122.72 mm^2	125.11 mm^2
Yield load	47.5KN	97.5KN	47.5KN	43.5KN
Ultimate load	70KN	130KN	70KN	75KN
Final length	64.1mm	57.5mm	64.1mm	62.1mm
Final diameter	6.8mm	10.1mm	6.8mm	6.3mm
Final area	36.31mm^2	80.11mm^2	36.31mm^2	67.92mm^2
Modulus of elasticity	190 MPa	190 MPa	190 MPa	194 MPa

(a)

(b)

(c) (d)

Fig.2. (a) SAE 1026 (b) SAE 4140 (c) SAE 5120 (d) SAE 8620 fracture specimen

TABLE VI
Tensile Test Results

Material Behaviour Parameter	SAE1026	SAE4140	SAE 5120	SAE 8620
Yield Stress, MPa	263.16	786.98	387.05	347.69
Tensile Strength, MPa	449.39	1049.31	570.4	599.47
% Elongation, Percent	33 %	15 %	28.2 %	24.7 %
% Reduction in area, Percent	54.05%	35.33%	70.41 %	45.71%
Plain Strain fracture Mechanics, MPa√m	22.94	68.61	33.74	30.31

B.Fracture Toughness and DBTT

Table VII shows Impact absorbed energy and average energy of each SAE specimen tested at 24°C, 0°C, -20°C, -40°C, and -60°C temperatures. Determine DBTT as that temperature corresponding to average of maximum and minimum impact energy. For SAE 1026, at impact energy of 19.5 J Ductile to brittle transition temperature (DBTT) is 1.2°C.

$$\text{DBTT} = \frac{\text{Highest energy} + \text{Lowest energy}}{2} = \frac{33+6}{2} = 19.5 \text{ J}$$

Table VII
Absorbed energy and average Impact energy of SAE specimens tested at different temperatures of SAE1026

Specimens	SAE1026		SAE4140		SAE 5120		SAE 8620	
Testing temperature (°C)	Impact energy (J)	Average energy (J)	Impact energy (J)	Average energy (J)	Impact energy (J)	Average energy (J)	Impact energy (J)	Average energy (J)
24	38	33	14	13	208	210	86	102
	28		12		212		118	
0	10	10	12	11	186	204	60	85
	10		10		222		110	
-20	6	6	8	9	200	176	22	44
	6		10		152		66	
-40	6	6	8	8	50	104	38	26
	6		8		158		14	
-60	6	6	8	8	16	16	20	17
	6		8		16		14	

The graph plots of Charpy impact energy in Joule versus test temperature are shown below for test specimens of SAE 1026, SAE 4140, SAE5120 and SAE 8620. For SAE 4140, SAE5120 and SAE 8620, the impact energy is 10.5 J, 113 J and 59.5 J respectively. The values DBTT for respective impact energy of specimens are -3°C,-38°C, and -10°C.

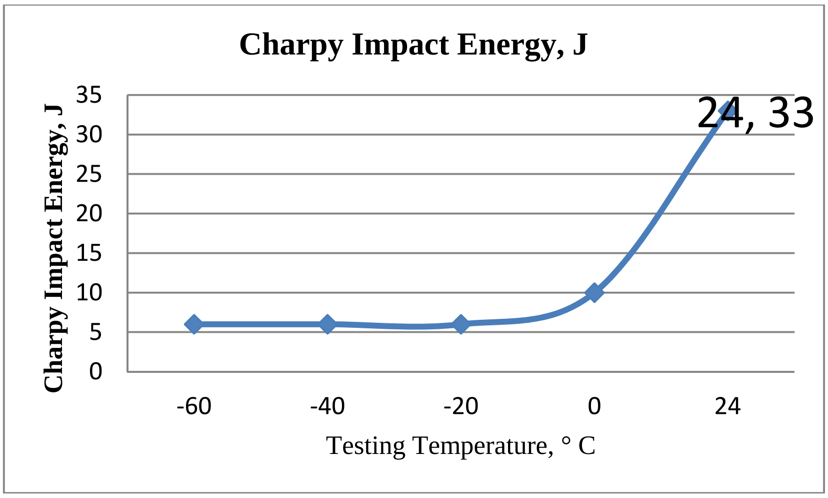

Fig.3. Impact energy Vs temperature of SAE1026

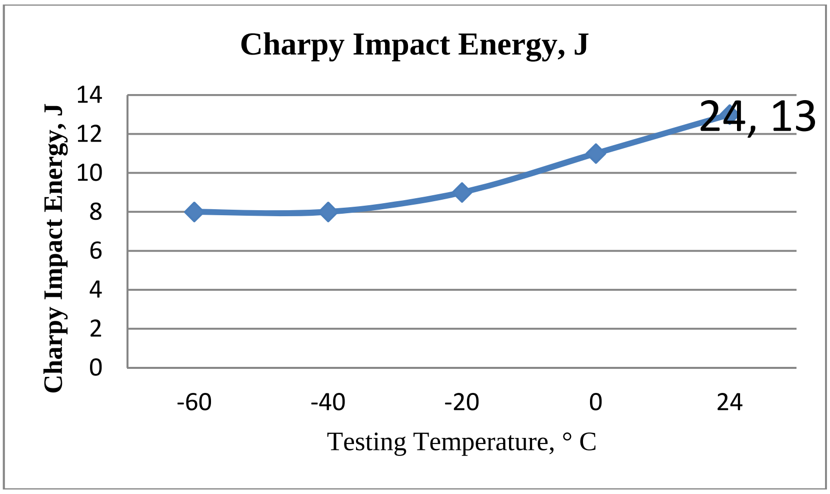

Fig.4.Impact energy Vs temperature of SAE4140

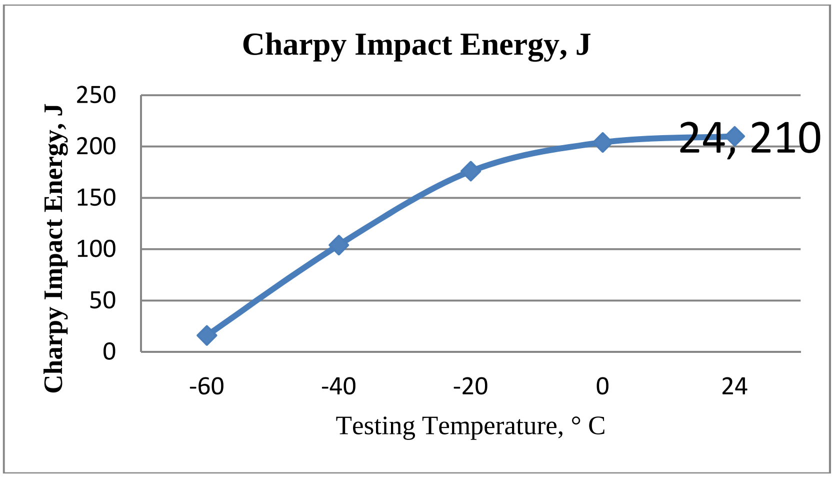

Fig.5. Impact energy Vs temperature of SAE5120

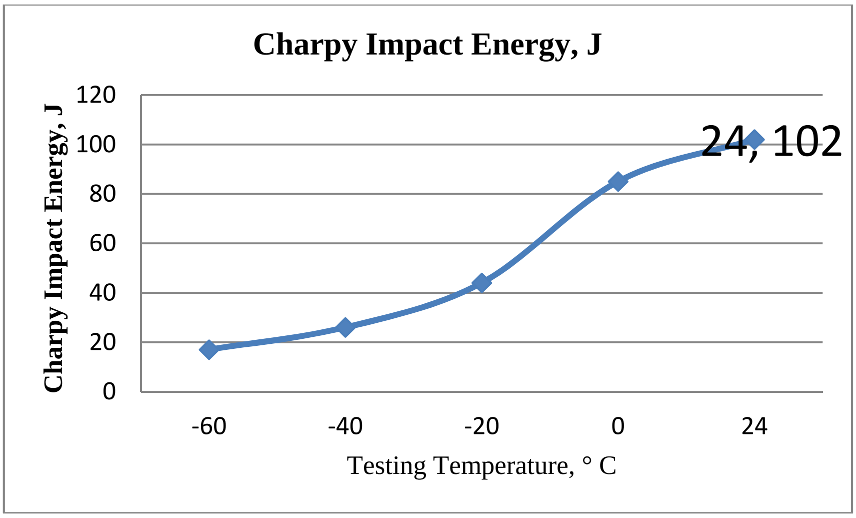

Fig.6. Impact energy Vs temperature of SAE8620

Fracture surface appearance:

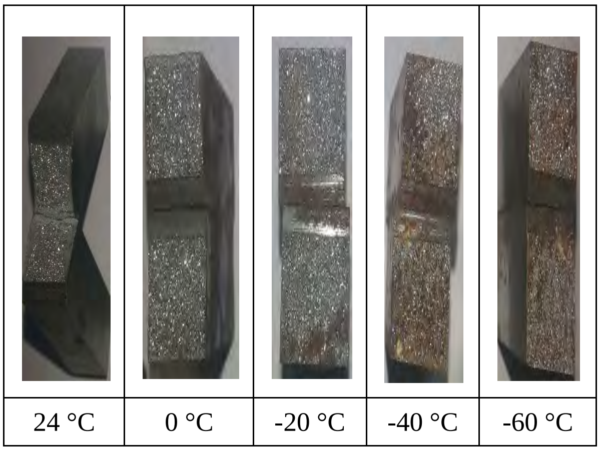

Fig.7.Fracture surface at different temperature for SAE1026

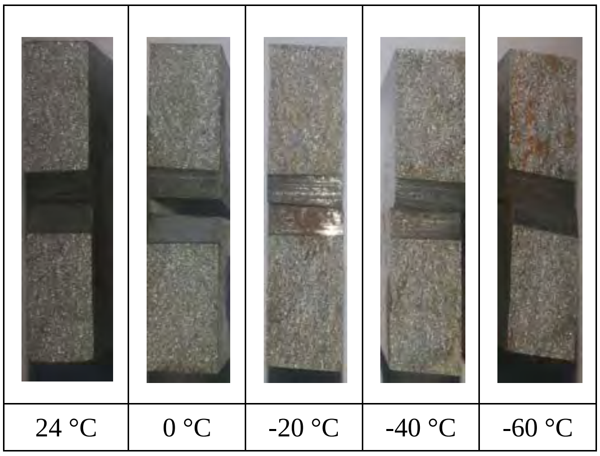

Fig.8.Fracture surface at different temperature for SAE4140

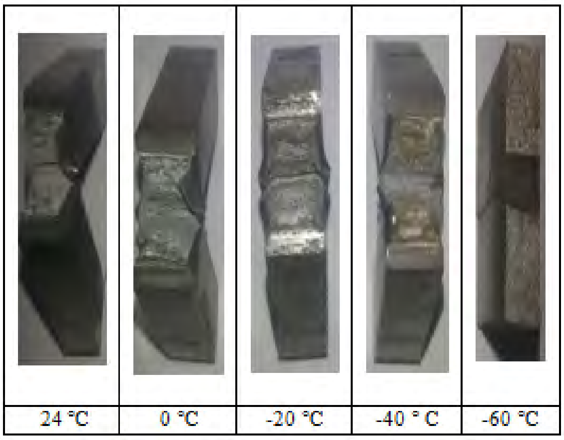

Fig.9.Fracture surface at different temperature for SAE5120

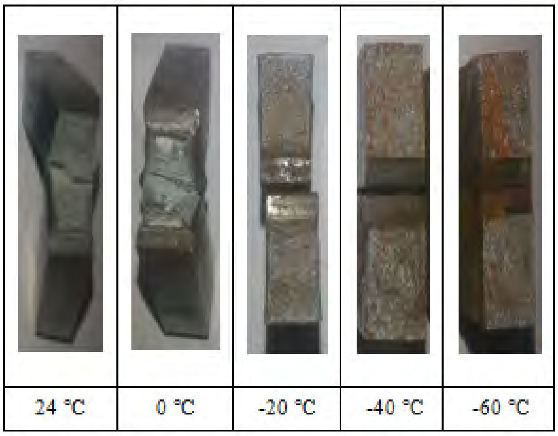

Fig.10.Fracture surface at different temperature for SAE8620

The larger values of impact energy are desirable from test. From Fig. 3 it shows the DBTT of SAE1026 is based on absorbed energy of 19.5 J is 1.2°C and upper shelf begins at approximately 24 °C with an absorbed energy of 33 J. The data shown in Fig. 4, 5 and 6 indicates that DBTT for SAE 4140, SAE 5120, and SAE 8620 upper shelf begins at approximately 24 °C with an absorbed energy of 13 J, 210 J and 102 J respectively. The upper shelf energy of SAE5120 is much higher than SAE 1026 and around twice of that of the SAE8620.

Note that, in comparison the ductile – brittle transition temperature (DBTT) for SAE 5120 is -38°C far below the 1.2°C of SAE1026 material. SAE 4140 shows higher Charpy impact toughness of 68.61 MPa $m^{1/2}$ at DBTT value of -3°C.

VI. CONCLUSION

This study predicted crashworthiness on automotive materials SAE1026, SAE4140, SAE5120 and SAE 8620 reveals that the classical procedure to predict the impact energy during a crash, fracture toughness and stress required for crack propagation from charpy impact test and tensile test. The materials SAE1026, SAE4140, SAE5120, SAE8620 shown that the ductile to brittle transition temperature, is about 1.2°C, -3°C, -38°C, -10°C based on 19.5 J, 10.5 J, 113 J, 59.5 J absorbed energy respectively. The fracture toughness predicted here for SAE1026, SAE4140, SAE5120, and SAE8620 are 22.94 MPa $m^{1/2,}$ 68.61 MPa $m^{1/2}$, 33.74 MPa $m^{1/2}$, 30.31 MPa $m^{1/2}$ respectively.

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