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Experimental Investigation of Using the Inversion of Thin Superplastic Tubes to Absorb the Energy of Car Collision

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Abstract— The protection of car occupants in car accidents from injuries and the protection of the car from damage is of vital importance. The available literature reveals that most of the published experimental work is carried out under quasi-static loading condition. although it is well established that the behavior of materials under dynamic and impact conditions is very different from the quasi-static condition. In this paper, utilization of an inverted circular cross sectional tube made of superplastic tin-lead alloy which is rate sensitive at low strain rate, 10^{-4} to 1 / s is used as an absorber of the collision energy from a car accident. The tube inversion was carried out over two die blocks of 3 and 10mm bend radii. The mechanism and mode of deformation is presented and discussed. Finally the obtained results are presented and discussed. Don't use all caps for research paper title.

Index Terms— Experimental investigation, Inverted tubes, Superplastic tin lead alloy, Energy absorption, Car collision.

1 Introduction

THE collision energy from car accident should be absorbed be absorbed or dissipated by some means to protect the car occupants and to avoid or reduce the car damage. Nowadays, due to increase in the number of population and the advances in technology have led to higher speeds and massive automobiles and aircrafts which can cause more serious injuries to people and damage to the costly structures themselves. In the 21st century people, now more than ever, educated and vocal enough to demand higher degrees of personal safety and protection, [1]. This hammers on the need for the design of safety measures especially the shock or energy absorbers. The ideal situation to deal with the problem is to design and manufacture protection devices and systems which can interact and absorb the collision energy as fast as possible and in a controlled manner before it reaches the occupants of the vehicle taking into consideration that the crash takes place within a period of mille seconds or even microseconds depending on the speed. The occupants may be subjected to different types of injuries depending upon the collision whether it is frontal, rear or side collision. Volvo Car Corporation conducted a research study on the different types of collisions and the injuries associated with them. Their study showed that:

i). More than one in two accidents is a frontal-collision which causes injuries to head, chest, legs and arms of the occupant body.

ii). One in every ten car accidents is a rear-end collision. This causes the neck to be subjected to a catapult movement resulting in a whiplash takes place in less than one tenth of a second.

iii). One in every ten car accidents is a side-collision which pushes the side of the car into the cabin and hits the occupants. It takes place within a period of one tenth of a second.

To protect against these damages, the following systems were developed: a safety cage, air bags, energy absorbing interior, self-adjusting inertia reel seatbelts with pretensions' on all seats and crumple zones with a number of energy absorbing members distributed at different points in the front of the car. The devices used for protection are usually one shot items i.e. once they have been deformed they are discarded and replaced. Their repeatability and reliability in use are of great importance.

The available literature on car accidents and crashworthiness is voluminous and the subject is very well established however, its treatment as a single discipline has yet to be generated, [1-18]. Careful examination of the literature reveals that most of the published work has been carried out on ordinary engineering materials and tested under quasi-static loading conditions, i.e. at low strain rate whereas the collision or impact situation is a high strain rate condition where the material behaves in a different manner. Therefore, the implication of designing an energy absorbing device or system on the basis of its quasi-static response and neglecting the inertia effects is unrealistic; therefore it is anticipated that the use of a rate sensitive material within the quasi-static range of deformation, (10^{-4}/s to 1 /s) in dealing with this problem. Hence, the superplastic tin lead alloy was chosen which has three advantages one as a superplastic material it can be formed to a large strain and second its rate sensitivity at low strain rate which can be obtained on the normal Universal testing machine at room temperature as most superplastic materials they require heating to get the superplastic behavior and third it can be reused after melting.

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1.1 Different Types of Car Collision and Protection Systems

The car collision may be frontal, rear end or side collision. The damage percentage depends on many parameters e.g. car weight, speed, driver experience etc. In 1992 Volvo Car Corporation conducted a study on the distribution of accident types and found that more than one accident in two is a frontal collision, one in every ten car accidents is a rear one and three in every ten car accidents are side ones. The car damages caused by these collisions are: in frontal collision, the front of the car is deformed and the car is retarded rapidly, while the occupants continue to move forwards. In the rear-end collision, the back of the car deforms and the occupants move backwards. In side impact, the side of the car is pushed into the cabin and hits the occupants

To protect the occupants from these injuries, different systems were designed and manufactured and used in cars. These are:

1. Crumple zones with s number of energy absorbing members at different points in the front of the car. 2. Safety cage
3. Airbags. 4. Energy- absorbing interior. 5. Anti- submarining guard on all seats. 6. Self-adjusting inertia=reel seat belts with pretensioners on all seats. The following protection systems: 1. Self-adjusting inertia=reel seat belts with pretensioners on all seats. 2. Side airbags. 3. Side impact protection systems. 4. Energy absorbing interior.

1.2 Types of Injuries of Car Occupants

The most frequent injures of the car occupants from frontal collision are heads, legs, chests and arms while in rear end collision, the injuries of the occupants are mainly the necks and injuries of the head, chest and arms in the side collision

2 Procedure for Paper Submission

2.1 Materials

The following materials were used: high purity tin of 99.7 % purity and Lead of 99.97 % purity with the following weight percentages 61.9 % Tin and 38.1 % Lead which corresponds to the eutectic composition were used for manufacturing the tubes. Die steel D2 of the chemical composition shown in Table 1 was used for manufacturing the extrusion dies and all the die blocks which were used for folding and inverting the tubes.

Table 1: Chemical composition by weight of die steel D-2 and the die blocks

Elemet	C	Si		Cr	Mo	V	Fe
Weight%	1.51	0.32	0.27	11.6	0.75	0.91	84.64

2.2 Equipment and Experimental Procedures

The experimental procedure started by manufacturing the main extrusion die. The schematic drawing of the direct extrusion die, its photograph and the mandrel which were designed and manufactured for extruding the superplastic tin-lead alloy work pieces, the tubes, are shown in Fig.1 (a), (b) and (c) respectively, followed by the manufacturing of the inversion die which was used for inverting the tubes. The assembled inversion die and its parts with their dimensions are shown in Fig.2.

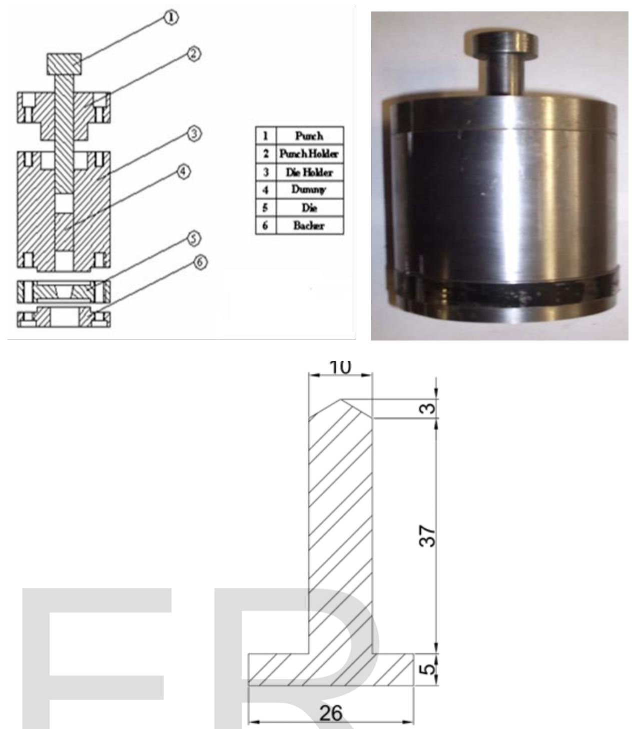

Fig.1: (a) Schematic drawing and photograph of the main extrusion die and (b) Mandrel

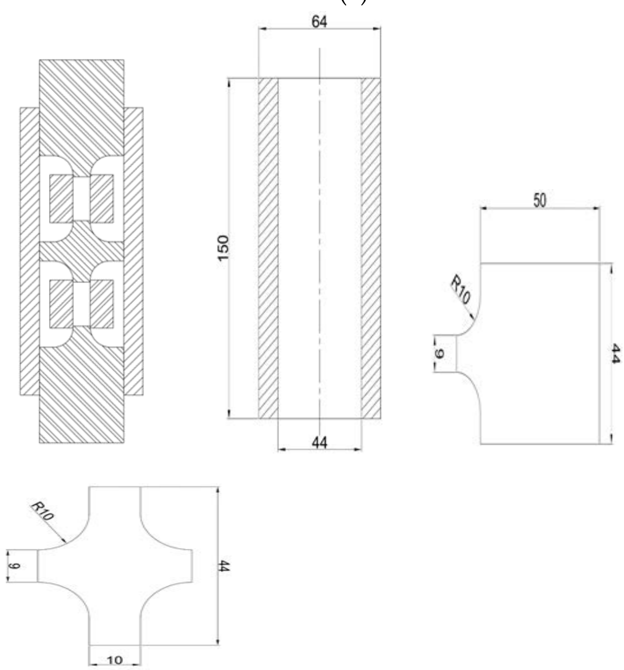

Fig. 2: schematic drawing of the inversion tube die and its parts. All dimensions are in mm

3 RESULTS AND DISCUSSION

3.1 Mechanical Behavior of the Work piece Material, Superplastic Tin-Lead Alloy

The mechanical behavior of the work piece material at different strain rates was determined from the autographic records of the compression test on cylindrical specimens of 10nmm diameter and 10mm height, i.e. of aspect ratio = 1 at five different cross head speeds namely: 0.1, 0.2, 2, 20 mm/ min. giving strain rates of 3.33×10^{-4}, 5.55×10^{-4}, 5.55×10^{-3}, 5.55×10^{-2} and 1.4×10^{-1} /s using an Instron machine of 250 KN capacity. The autographic records were redrawn on one figure, Fig. 3 from which the representative stress - representative strain was obtained , Fig. 4, and finally log representative stress – log representative strain was determined, Fig. 5. It can be seen from these figures that although the material is compressed in the quasi-static loading conditions, it showed a clear rate sensitivity for example, referring to Fig. 4, at strain E = 0.6, the flow stress is 100 Mpa at strain rate = 0.14/s, whereas the flow stress is 45 Mpa at the same strain and 3.33×10^{-4}/s, giving a strain rate sensitivity, RS, of, 2.2. It is worth mentioning in this respect that if a conventional engineering material is tested within this range of strain rate its flow stress would not have altered, [3]. The rate sensitivity index of the work piece material as determined from Fig.5-3 is 0.14 66. Hence the mechanical behavior of the work piece material can be represented by the following equation:

$$\sigma = 158.85\, \acute{\varepsilon}^{\,0.1466}$$ Where σ is in MPa..

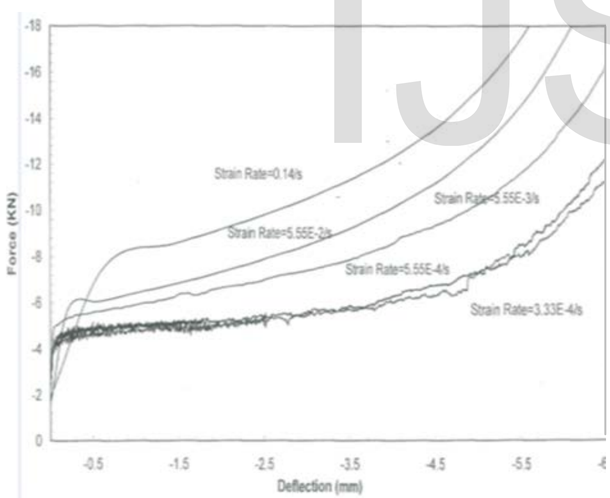

Fig. 3: Autographic record of compressing tin-lead alloy at different strain rates

3.1 Mechanical Behavior of the Work piece Material, Superplastic Tin-Lead Alloy

3.2.1. Preliminary Tests

Before trying the manufactured extrusion and inverted systems, preliminary tests were carried on plasticine and lead. Their autographic records are shown in Figs. 6 and 7 respectively. After the tests were successful, they were tried on the superplastic material.

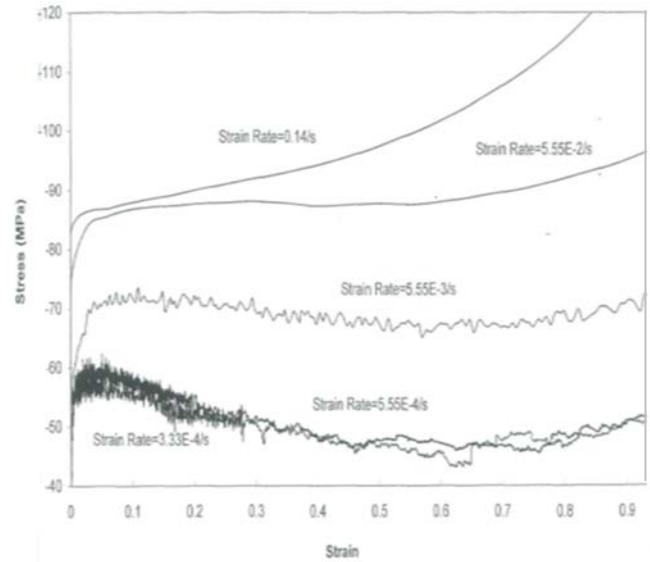

Fig. 4: Stress- strain curves of superplastic tin-lead alloy

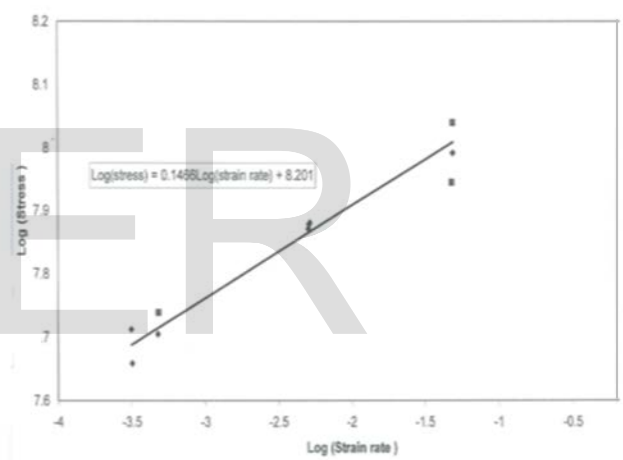

Fig. 5: Log stress vs. Log strain of superplastic tin-lead alloy

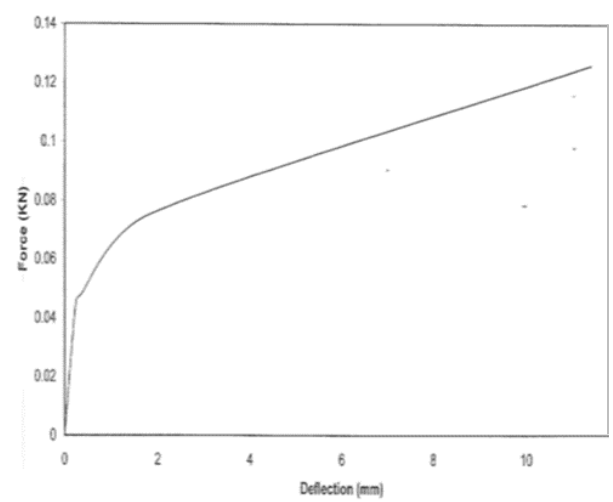

Fig. 6: Autographic record of direct extrusion of plasticine

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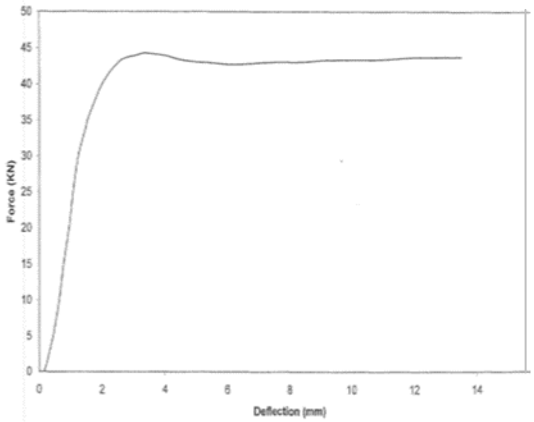

Fig.7: Autographic record of direct extrusion of pure lead

3.2.2. Force and Energy Absorption by the inverted tube made of Superplastic Tin-Lead Material at different Strain Rates and Displacement

The force and energy absorbed at any displacement at different strain rate were determined from the corresponding autographic records of Figs 5 and 6. The force was obtained directly from the curve while the absorbed energy was determined at specific strain and displacement from the area under the curve using a plan-meter, Fig.8. Variation of the force and absorbed energy with the deflection i.e. the moved displacement, at different strain rates are shown in Tables 2 and 3 respectively.

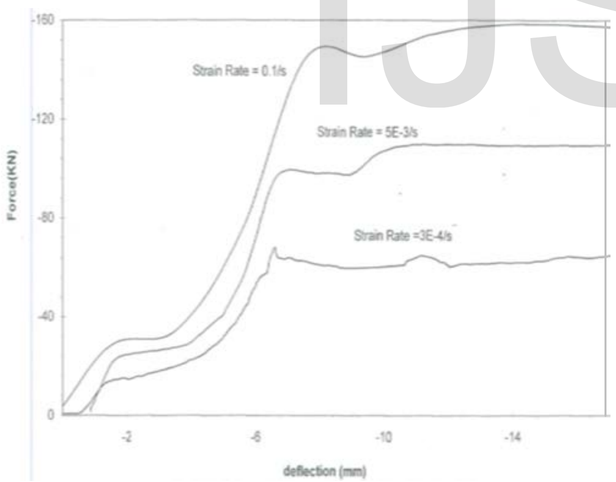

Fig. 8: Autographic records of direct extrusion of superplastic tin-lead alloy at different strain rate

3.2.3. The Mechanism and Mode of Deformation of Tube Inversion

The observation of the experimental tests indicated that the mode and the mechanism of deformation of the inverted tube using the small die profile radius, 3mm, is quite different from that of the inversion using the large die profile radius, 10mm; therefore each one is discussed on its own merits.

Furthermore, The observations of the experimental tests indicated that that the mode and the mechanism of deformation of the inverted tube using the small die profile radius, 3mm, is quite different from that of the inversion using the large die profile radius, 10mm; therefore each one is discussed on its own merits. Only the mode of deformation around 3mm die profile radius will be discussed in this paper.

3.2.2.1 Mechanism and mode of deformation for the 3mm die profile radius

The deformation of the tube around the 3mm die profile radius consists of three different stages:

a). Reduction of the tube height under the compression load accompanied by bending of the tube, at its ends around the die profile radii as indicated by the part of the autographic record 0-1. With the continuation of the bending process, the already bent pat of the tube starts to open up i.e. unbending takes place causing straightening of the bent part. This is represented by the part 1-2 on Fig. 9. This figure illustrates that point 1 represents an inflection point on the autographic record.

After straightening, expansion of the tubes takes place from the internal diameter. This part is represented by part 2-3 on the autographic record which is almost a straight line relationship between the force and deflection. Furthermore, it was noted that all the outer diameters of the inverted tubes have increased while their inner diameters have decreased; even complete closure had taken place in some of the tubes.

Cavity closure does not depend only on the end friction at the die-work piece interface as repeatedly reported in the literature, [18], but also depends on other parameters, e.g. strain rate, the geometrical shape of the platens if flat or at angle, reduction in height and the inner diameter to the outside diameter ratios of the specimen, (Di/Do).

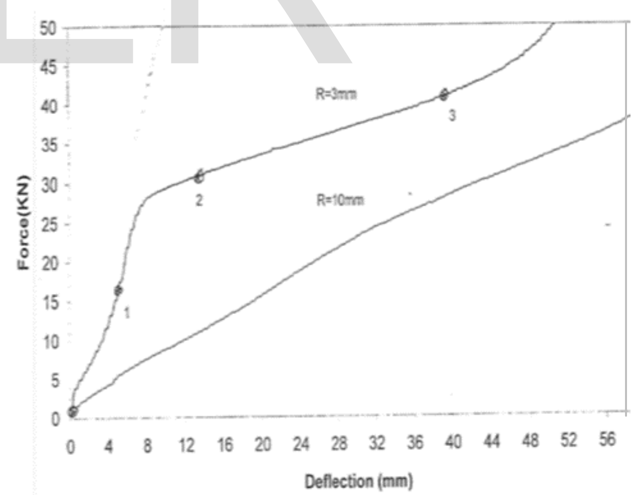

Fig. 9: Autographic record of superplastic tube inversion at 3mm and 10mm die profile radii and 4.2×10^{-2} strain rate

4 Conclusion

Within the experimental limitations the following point are concluded:

1- The use of superplastic Tin-Lead alloy in the quasi-static loading condition is very successful to simulate the behavior of engineering materials when subjected to dynamic loading.

2. In utilizing the tube inversion system, if the collision force

is high and protection is needed against it then; it is advisable to use multi-systems in parallel. If the object is to absorb the collision energy rather than the force then it is advisable to use them in series.

3. The utilization of the concept of plastic work consumed in deformation represented by extrusion and tube inversion system has been proved to be successful methods for absorbing the energy of any collision problem in general and of automobile accidents in particular, hence protecting the car from damage and the occupants from injures.

4. The effectiveness of the extrusion system within the strain rate sensitive region, 10/ 10^2 /S to 1 /S is 2.3 times the region prior to it, i.e. below ; whereas the effectiveness of the inversion tube system is 6.07, i.e. 2.64 times the direct extrusion system within the same strain rate region.

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