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Influence The Arrangement of Hybridization on Parameters of Crash Worthiness

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تأثير الترتيب في التهجين على بارامترات قابلية امتصاص السحق

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Abstract

The paper presents an experimental study on the quasi-static lateral crush performance of metal–composite hybrid tubes containing a filament-wound E-glass fiber-reinforced epoxy over-wrap around cylindrical metal tubes. The quasi-static lateral crush resistance of the hybrid tubes is compared in terms of the maximum load, mean crush load, crush energy, and specific energy absorption. The deformation modes effect of these tubes is described by the arrangement of hybridization on crashworthiness parameters.

Keywords*: Composite, Metallic and hybrid tubes; Energy absorption; Lateral compression crushing*.

الملخص

هذا البحث يقدم دراسة عملية لمدى تأثير الترتيب لطبقات التهجين على قابلية امتصاص طاقة السحق، حيت تم تصنيع عينات أسطوانية الشكل مكونة من ثلاثة طبقات من المواد المركبة مع أسطوانة معدنية (منخفضة الكربون) بحيث تكون طبقات المواد المركبة داخلية في العينة الأولى وتكون خارجية في العينة الثانية، وبعد عملية التصنيع تم تعريض العينات لحمل محوري شبه ساكن، وعدد الاختبارات لكل نوع هي ستة اختبارات، والبارامترات التي تم أخذها في عين الاعتبار للمقارنة هي كمية الطاقة الكلية الممتصة والطاقة النوعية لكل عينة. أظهرت النتائج أن التهجين له تأثير إيجابي مقارنة بعينات الحديد ولم يظهر أي اختلاف مهم في عملية الترتيب حيث كانت النتائج متقاربة.

الكلمات الدلالية: المواد المركبة، الأنابيب الهجينة، السحق المحوري، الطاقة الممتصة الكلية والنوعية.

1. Introduction

With the increasing of number of road vehicles, traffic accidents have also increased and this has caused the number of occupants' death and injuries to increase. During the last decades, researchers have paid great interest towards the direction of saving passengers by improving the crashworthiness of vehicles body (Thornton, 1979; Thornton and Edwards, 1982; Mamalis *et al*., 1991; Hamada and Ramakrishna, 1995; Mamalis *et al*., 1997; Ramakrishna and Hamada 1997; Khalid *et al*., 2002; & Abdewi *et al*., 2006). As a result of that occupant's convenience and safety become the most essential requirements and the primary factors in

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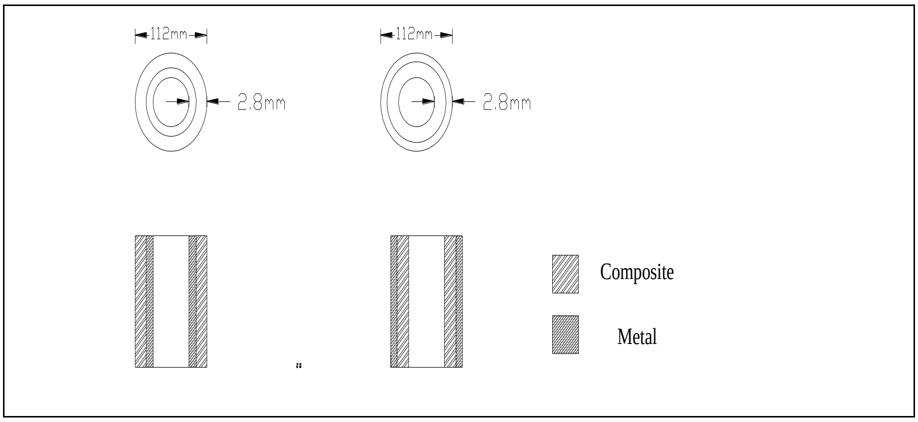
designing and manufacturing of all kinds of vehicles (cars, ships, airplanes, ...etc.). In the past, designers tried to avoid crash severs using steering (handling), acceleration and brake systems, driver and passenger safety systems such as collapsible steering column, seat belts, airbags, sturdy seatbacks, functional door latches, front and rear crumple zones, metallic energy absorber devices such as bumpers, rails and side effect beams (side impact zones). All of these items have been available since the early 1970's, however, many were not found even in vehicles produced in 1990's. These features may or may not be present in a particular vehicle and may or may not work even if present. Most of these safety features can fall prey to defect. Examples of automobile defects include: seatbacks that crumple on strong impact, door latches that open in a collision, seatbelt rips, seatbelt latches that to come faulty, malfunctioning seatbelt retractors, ...etc. Therefore, great deals of research and developments have been carried out over the years to design and integrate these systems and avoid their drawbacks. The researcher's effort focused towards finding a highly reliable system to ensure passenger safety or at least to alleviate severe impact during collisions. The results that proved a proper solution to the problem of crashworthiness; that is by inserting an effective composite collapsible energy absorber device in the vehicle body; for example, in front of vehicle body behind the bumper, the side-beams on which the engine is mounted or in the sidewall of the cars' doors. Collapsible energy absorbers function to minimize the kinetic energy of the vehicle in such way that the deceleration of the second collision (i.e., occupants into vehicle interior) does not exceed the limit beyond which severe internal injury such as irreversible brain damage or death occurs (Mazumdar, 2001). Development and improvement of these elements continue towards the direction of achieving their optimum design. Due to this study focused on using composite structures as energy absorber elements due to their superior properties. Composite structures serve to reduce the weight of the vehicles and in turn help the designer to meet the design requirements of vehicle manufacturing and customers.

2. Experimental Work

2.1 Fabrication of GFRE-Metal hybrid tube

As shown in Figure (1.a, b), the metal cylinders wrapped with glass/epoxy. The metal tube was machined from thin cylinders to form circular tube with external diameter of 112 *mm* and length of 150 *mm*. The reinforced tubes were wrapping the metal cylinders circumferentially (external, internal) with a composite material of winding. The composite material used were woven roving glass fiber and epoxy resin with hardening with volume fraction of fiber was 51%. The composite thickness for three layers is around 1.8 *mm* ±0.05 *mm*. With same material used for composite material specimens as shown in Table (1).



a) Schematic diagram of specimens

b) Photographs of specimens

Figure 1. Type of metal-GFRE hybrid specimen and GFRE-metal hybrid specimen

Table 1. Types of used constituents

Material	Manufacturer
Epoxy resin	UK Epoxy Resins UKH 137 Epoxy
Hardener	UK Epoxy Resins UKH 136 Hardener
Woven roving E-glass fiber	Synthetic fiber from PPG. Ind. Inc., USA

The test material used for fabrication part of metallic is low carbon steel. It has mechanical properties as shown in Table (2) According to (DIN 1623-1) "German system of coding". In order to be more confidant of the used material spectrum analysis test has been performed and the results obtained are recorded in Table (3).

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Table 2. Mechanical properties for low carbon steel

Classification	Standard	Grade	Y.S• (*N/mm*)	UTS° (*N/mm*)	%E* (*mm*)	Hardness HRB
Cold rolled sheets	DIN1623-1	St 12-03	260	350	29	65

• Yield strength   ° Ultimate tensile strength   * Elongation

Table 3. Compositions of IRON specimen

Composition	Value, (%)	Composition	Value, (%)
C	0.0256 - 0.0414	*Mo*	0.0187 – 0.0194
Sil	0.0224 – 0.0242	*Cu*	0.1806 – 0.1852
S	0.0015 – 0.0046	*Ti*	0.0024 – 0.0026
Mn	0.1071 – 0.1132	*Sn*	0.0081 – 0.0086
P	0.0007 – 0.0016	*Pb*	0.0016 – 0.0032
Nil	0.1146 – 0.1190	*Zn*	0.0040 – 0.0057
Cr	0.0563 – 0.0591	*Fe*	99.43

2.2 Test Procedures

2.2.1. Quasi-Static Crushing Test

As in the literature, one of the common ways used for investigating and understanding the effect of various variables on crushing behavior is to perform crushing tests. In this study, a comprehensive program of lateral quasi-static compression crushing tests was performed according to the ASTM D1621 standards. The objectives of the tests were to study the crushing behavior of the currently under study specimens and to investigate the effect of the design parameters on energy absorption capabilities of diffident tested model. An FORM+TEST servo hydraulic digital-testing machine used as shown in Figure (2) with full-scale load range of 4000 *kN* was used to perform experimental testing program. The specimens were set and then compressed between two parallel flat steel plates set parallel to each other prior to initiation of the tests; one end is stationary and the other one is moving at a constant cross head speed of 2.5 *mm/min*. A displacement control method with the same crosshead speed was applied in compressive direction. The specimens were compressed for distance equal to approximately the specimen diameter for lateral test. As a result of the crushing test, load-displacement curves were plotted.

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Figure 2. Universal testing machine

In addition to direct observation, series of photographs were recorded during each test to study the history of the crushing process. Care was taken to obtain accurate results. The specimens were lateral compressed by using the same machine and conditions. To raise the confidence of the tests and to determine the significance of response variability for each case, at least three specimens were tested under the same nominal condition.

2.2.2. Load-displacement Curves and Crashworthiness Parameters

The load-displacement curve plays an important role on the findings of the crashworthiness parameters and on description of crushing response. In this study, load-displacement curves obtained from average the load-displacement points of three replicated tests of each kind of specimen (all the specimen have the same geometry, material, and test conditions) were performed. Different parameters are used to measure the crashworthiness performance. The crashworthiness parameters (*CWPs*) used in this research are; specific energy absorption (E_{sp}), and total energy absorption(E).

3. Results and Discussion

Results and typical load paths together with deformation histories were presented and discussed. load-displacement curves are the main source of many valuable data such as: initial failure load, average load and total energy absorption. In consequent to that, specific energy absorption, energy absorption per unit length, Crush Force Efficiency (CFE), Stroke Efficiency (SE) were calculated. From the typical load paths with deformation histories, the response of specimens to lateral crushing loads, failure mechanisms and failure modes were identified and discussed with the help of digital photos that wherever captchered. The crushing failure modes were investigated corresponding to the critical load, as well as the stresses concentration regions.

3.1 Lateral Crushing Test

Since the mode of failure and the pattern of load-displacement curves of the various specimens' tubes are different, each has been discussed independently in the following sections.

3.1.1. GFRE-Metal-Hybrid Specimens

As shown in Figure (3) the crushing load increases until the compression is about 18 *mm* when full resistance is developed with 2700 *N* load, then the resistance of the specimen small decrease, afterwards the loading increase step-by-step until the compression is about 38 *mm* when full resistance is developed with 3400 *N* load, and continuous the compression up and dawn, this behavior seems to continue until complete crushing when the load increases sharply.

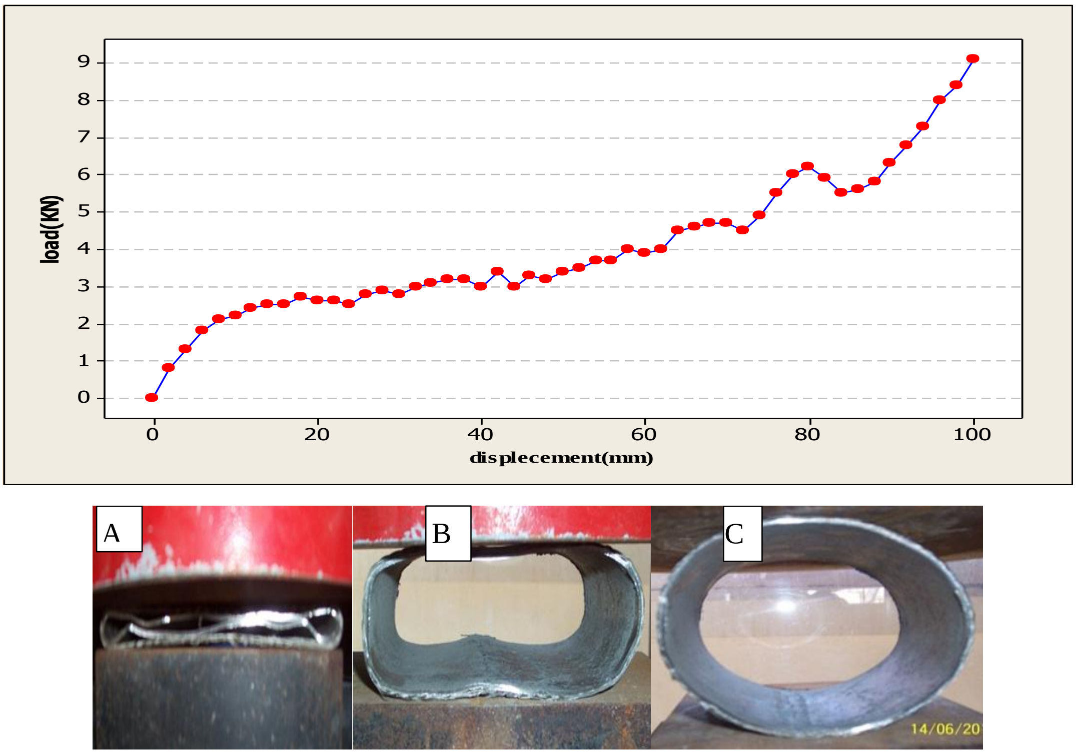

Figure 3. Load-displacement curves and deformation history of GFRE-Metal hybrid specimen under lateral crushing load

3.1.2. Metal-GFRE hybrid specimens

As shown in Figure (4) the crushing load increases until the compression is about 54 *mm* when full resistance is developed with 5400 *N* load, then the resistance the specimen small decrease, immediately after this stage four longitudinal fracture lines are observed to have developed in layers of composite material. The fracture diametrically opposite to each other at about 90º angle and plastic deformation in metal as seen in, the loading increase step-by-step until the compression is about 88 *mm* when full resistance is developed with 5800 *N* load, this behavior seems to continue until complete crushing when the load increases sharply.

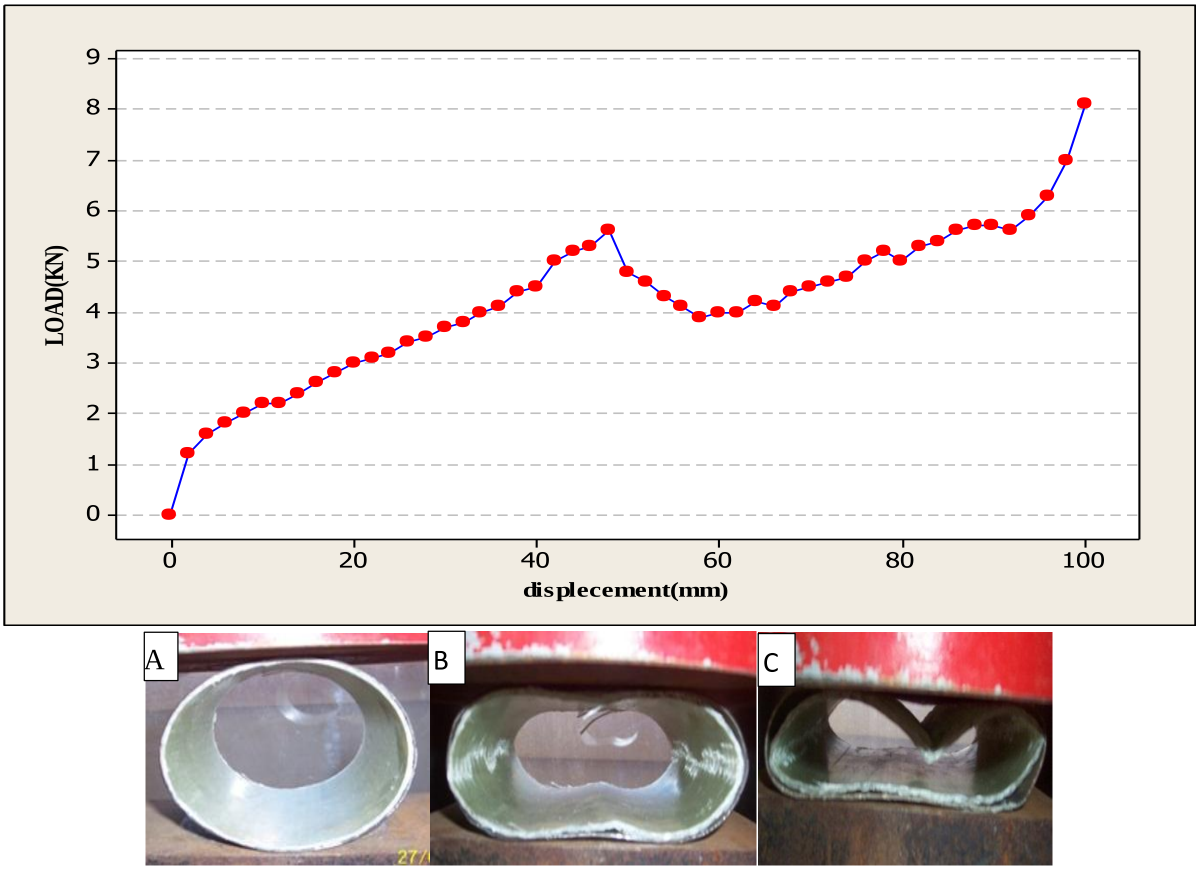

Figure 4. Load-displacement curves and deformation history of Metal-GFRE hybrid specimen under lateral crushing load

3.2 Crushing Energy Absorption

The important factors which are used as a measure of the efficiency of performance of energy absorbers. Crashworthiness performance parameters are useful in comparing different composite materials and structures. Crashworthiness performance can be estimated by knowing the following parameters:

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3.2.1. Total Energy Absorption (E)

The total energy absorbed or the total work done (W_t), in crushing of composite specimens is the area under the load-displacement curve. It can be obtained by numerical integration of the load displacement curve;

$$W_t = \int_{Si}^{Scr} P_{av}\, dS \;\; = P_{av}(S_{cr} - S_i) \qquad \text{……………………. (1)}$$

where, S_i and S_{cr} are the initial and final useful crush stroke and P_{av} is the mean crush load which obtained by averaging the applied loads during post crush stage as show in Figure(5). The load-deformation characteristic is a measure of the energy absorption capacity. It differs from one structure to another, and it depends on the mechanism of deformation involved and the material used.

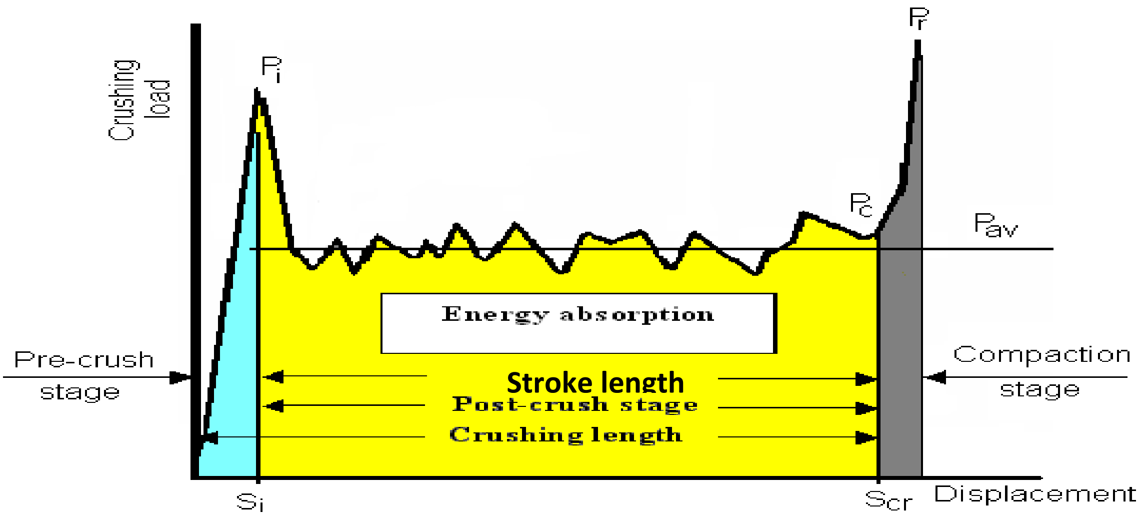

Figure 5. Schematic representation of a typical load-displacement curve of a composite tube with its main parameters

To compare different materials or different geometry for specimens, it is necessary to consider the specific energy. The specific energy is defined as the amount of energy absorbed per unit mass of crushed material. Therefore, the specific energy (E_{sp}) that depend on the structure material was used for comparing the energy absorption of all specimen type. Specific energy absorption (E_{sp}) can be calculated as;

$$E_{sp} = \frac{W_t}{m} \qquad \text{……………………. (2)}$$

where, m is the mass.

After completed all lateral crushing test the results obtained from these tests presented in Table (4), and representation by curve as shown in Figure (6).

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Table 4. Crashworthiness parameters of lateral tests for specimens

Specimen type	Max. Load P_{max}, (*kN*)	Mean Load $\bar{P}$, (*kN*)	Energy Absorption E_T, (*kJ*)	Weight (*kg*)	Specific Energy (*kJ/kg*)	CFE (%)	SE (%)
Comp-met hybrid C/M	6.2	3.988	0.279	0.590	0.470	63.3	80.4
Met-comp hybrid M/C	5.7	4.169	0.284	0.590	0.481	73	82

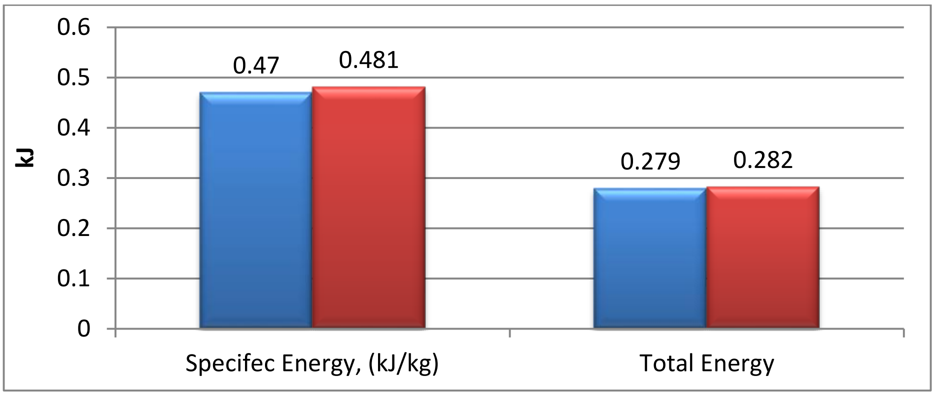

Figure 6. Total absorbed energy and specific energy of type specimens subjected to lateral crushing load

4. Conclusion

The metallic tubes fail by plastic buckling, however, the GFRE tubes collapse by a combination of fracture processes. The GFRE tubes have exhibited an effective and stable energy absorption phenomenon in the laboratory testing. Though the failure of GFRE tubes has been due to the formation of four fracture lines, all models have almost the same kind of failure mode. It was noticed that Hybridization has positive effect on crashworthiness parameters. It is found that C/M and M/C models have good energy absorption characteristics compared with pure metallic specimens. The arrangement influence of hybridization on energy absorption characteristics are low, the specific energy absorption of hybrid specimens was approximately even. However, there is no significant effect of hybrid sequence, i.e. there is no much difference between M/C and C/M specimens with respect to crashworthiness parameters. So can be used in a variety of marine applications such as passenger ferries, power boats, buoys, … etc. Because of their energy absorption under crush test.

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