STUDYING THE EFFECT OF LOW SPEED IMPACT ON THIN WALLED CIRCULAR TUBES MADE OF COMPOSITE MATERIALS AND ALUMINUM ALLOY 2024-T135 [+]

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Abstract :

This paper aims to quantify the difference in amount of absorbed energy due to Impact on thin walled circular tubes that made from 2024-T135 aluminum alloy and that one made from composed material of the same dimensions. The two selected materials were subjected to the same Impact test conditions, which consist three different drop weights; each weight was dropped in three different impact speeds. The resulted deformations of the impacted specimens due to the drop weight and the impact speed were measured, then three terms were calculated depended on the measured deformation for each drop weight and impact speed, these are the mean impact load, specific energy absorption, and the absorbed energy. It was observed that the amount of absorbed energy is the same for the two selected materials under the same impact conditions, even when the measured deformation of the composite specimen is larger than that of the 2024-T135 specimen.

دراسة تأثير الصدمة بالسرعة المنخفضة على الانابيب دائرية المقطع ذات الجدران الخفيفة المصنعة من المواد المركبة و سبيكة الألمنيوم 2024-T135

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المستخلص:

تهدف هذه الدراسة الى معرفة الفرق بين استخدام الانابيب ذات الجدران الرقيقة دائرية المقطع المصنوعة من سبيكة الالمنيوم 2024-T135 و تلك المصنوعة من المواد المركبة بنفس الابعاد, من حيث مقدار الطاقة الممتصة من قبل تلك الانابيب نتيجة اختبار الصدمة, حيث تم تعريض المادتين الى نفس الظروف الخاصة باختبار الصدمة و التي شملت ثلاثة اوزان ساقطة, كل وزن تم اسقاطه بثلاثة سرع صدمة مختلفة. من خلال الاختبارات تم قياس مقدار التشوه الحاصل في العينة نتيجة الحمل الساقط و سرعة الصدمة, و على اساسه تم احتساب ثلاثة متغيرات مهمة هي متوسط حمل الصدمة, و الطاقة الممتصة النوعية, و مقدار الطاقة الممتصة الفعلية نتيجة الصدمة, حيث تم التوصل الى ان مقدار الطاقة الممتصة لكل مادة هي نفسها تحت نفس ظروف الصدمة, بالرغم من ان مقدار التشوه الحاصل في عينة المواد المركبة هو اعلى بكثير من ذلك الحاصل في عينة سبيكة الالمنيوم.

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Introduction :

For structures subjected to impact loading, crashworthiness is highly desirable and depends on energy absorption mechanisms of the system [1]. Among various energy absorbing structural components, circular and rectangular tubes have been the focus of crashworthiness research due to their wide spread applications in industries [2]. The use of thin-walled tubes collapsing plastically in axial compression is one of the most efficient means of energy absorption. These tubes are small in volume, easy o fabricate in weight, cheap, and stable during crushing.

Mohammad [3] investigated the compressive properties and crushing response of circular and square fiber glass reinforced plastic tubes subjected to impact testing at different temperatures, by using LS-DYNA explicit finite element software. A parametric study was also conducted to study the effect of inner hole, tube thickness (number of layers), winding angle and Yong modulus ratio (E_a/E_b), on the absorbed energy and specific energy absorption. The comparison of experimental results for failure mode, absorbed energy, crush distance and specific energy absorption for circular and square tubes at 30^0C, 40^0C and 50^0C, showed good agreement with those of numerical results.

Ayad [4] investigated impact process in different speeds on thin walled pipes made by Aluminum alloy (2024-T351). He suggested a mathematical model to calculate mean load, deflection value, and variation in force during deflection for one fold in static and dynamic states. The effect of fold factor and fold length on mean force and deflection were studied, too. The modeling results were compared with his experimental results and the comparison gave good identification. Finally, he discussed impact factor and impact stress, then he found that they are increased when impact speed increased.

The effects of shape memory alloy thin films embedded in composite plates for improving damage resistance of composite structures under low velocity impact were investigated numerically by **Eun-Ho Kim et. al.**[5]. Analysis model for SMA thin film was developed based on Lagoudas' model and implemented using the user defined material subroutine of the ABAQUS/Explicit finite element program. Composite damage model based on the Chang–Chang failure criteria was also implemented to consider progressive damage behavior.

Qing Hua Zhang, et. al.[6] investigated the microstructure and microstructural evolution near crater wall in Al–Cu–Mn alloy using optical and transmission electron microscopy after projectile impaction. The results show that three characteristic zones around the crater can be classified based on the different microstructure, i.e. deformation bands, dynamic recovery zone and adiabatic shear bands

This research aims to know the difference in amount of absorbed energy due to Impact on thin walled circular tubes that made from 2024-T135 aluminum alloy and that one made from composed material within the same dimensions and impact conditions, but by repeating the tests in different drop weights and impact speeds.

Selected Material For Experimental Work:

For comparison purposes, two materials were selected to produce thin walled tubes, there were 2024-T351 Aluminum alloy, and composite material constituted matrix of unsaturated polyester resin and reinforcing Glass fibers. The chemical composition of 2024-T351 alloy is shown in Table (1);

Table (1); chemical composition of 2024-T352 Al. alloy[4].

element	Si	Fe	Cu	Mg	Mn	Cr	Zn	Ti	Al
(wt%)	0.51	0.5	4.37	1.44	0.7	0.1	0.25	0.15	Rem.

The matrix of the composite material was unsaturated polyester resin which has many industrial applications. The chemical reaction that causes the hardening of the liquid resin is a free radical polymerization initiated by organic peroxides. The catalyst used is the methyl ethyl ketone peroxide, and in order to work at room temperature, cobalt naphthenate is added as an accelerator additive[7].

Glass fibers reinforcement was unique materials that exhibit the familiar bulk glass properties as well as fiber properties. The representative chemical compositions of glass fiber are given in Table (2);

Table (2); chemical composition of glass fiber[8].

element	Silica	Calcium oxide	Al	Boron oxide	Soda	Calcium fluoride	Total minor oxide	Magnesia
(wt%)	0.51	0.5	4.37	1.44	0.7	0.1	0.25	0.15

Specimen Design and Preparation:

All specimens were designed and machined to meet the standard specimen dimensions for impact tester (DIN 2250) and the other mechanical tests such as tension, compression, and shear tests. The aluminum specimens were prepared by machining processes, while the composite material specimens were manufactured using mechanical wet filament technique by winding angle of 45^o with 0^o fiber direction [3]. The selected specimens for impact test had circular cross section of the following dimensions (length=100mm, inner diameter=15mm, and thickness=1.5mm).

Mechanical Properties:

Some of mechanical properties of the two selected materials should be known before starting the impact studies, these are tensile and compressive strengths, modulus of elasticity, and modulus of shear. Thus, tensile and compression tests were achieved applying standard specimens [9][10] at room temperature (about 30 ^oC) to obtain these properties. The results are illustrated in Table (3);

Table (3); mechanical properties of the tested materials.

	σ_t (MPa)	σ_c (MPa)	E (GPa)	G (GPa)
2024-T352 Al. alloy	457	163	71	27.5
Composite material	428	234	13.8	4.4

where; σ_t : is the tensile strength,
σ_c : is the compressive strengths,
E : is the modulus of elasticity, and
G : is the modulus of shear

Calculating Impact Energy Parameters:

This investigation aims to determine the absorbed energy by the selected specimens due to impact of dropped weight at three different values and in three different impact speeds.

The Specify Energy Absorption (*SEA*) is calculated as the mean impact load (P_m) divided by the mass (*m*), which is (0.05Kg) for the aluminum specimen and (0.03Kg) for the composite specimen, per unit length (*L*) (linear density) of the specimen[11], which is equal to (100 mm) according to the standard (DIN 2250), as following;

$$SEA = P_m\left(\frac{L}{m}\right) \ldots\ldots.(1)$$

Thus ; $SEA = 2P_m$ ......(1-a), for aluminum alloy specimen, and;

$SEA = 3.334P_m$ ......(1-b), for composite specimen.

While the absorbed energy by the specimen (*E*) can be calculated by[4];

$$E = P_m\delta \ldots\ldots.(2)$$

Where δ is the deflection

The deflections of each specimen at each impact load and speed were recorded until failure. The deflections (δ) were determined experimentally by measuring the difference in the specimen length (ΔL) due to impact deformation.

The mean crushing load can be calculated by[4];

$$P_m = \frac{MV^2}{2\delta} \ldots..(3)$$

Where; *M* is the drop weight (Kg), and

V is the impact velocity (m/s).

Impact Test:

A drop weight impact tester was used to impact specimens of both selected materials at three different drop weights (*M*) and speeds (*V*) as shown in Tables (4) and (5), respectively.;

Table (4) drop weights used in the Impact test

Drop weight (Kg)		
M_1	M_2	M_3
1	3	5

Table (4) impact speeds used in the Impact test

Impact speed (m/s)		
V_1	V_2	V_3
3.7	4.2	4.7

Results:

The results of impact test for both selected materials are shown in Tables (6)-(14);

Table (6); Impact test results; M_1, V_1

Calculated terms	2024-T351 Aluminum alloy	Composite material
δ (mm)	0.5	8
P_m (KN)	13.69	0.855
SEA (KJ/Kg)	27.38	2.852
E (J)	6.845	6.84

Table (7); Impact test results; M_1, V_2

Calculated terms	2024-T351 Aluminum alloy	Composite material
δ (mm)	0.7	11.2
P_m (N)	12.6	0.787
SEA (KJ/Kg)	25.2	2.625
E (J)	8.82	8.814

Table (8); Impact test results; M_1, V_3

Calculated terms	2024-T351 Aluminum alloy	Composite material
δ (mm)	0.9	14.5
P_m (N)	12.272	0.767
SEA (KJ/Kg)	24.544	2.556
E (J)	11.044	11.121

Table (9); Impact test results; M_2, V_1

Calculated terms	2024-T351 Aluminum alloy	Composite material
δ (mm)	1.6	27
P_m (N)	12.834	0.76
SEA (KJ/Kg)	25.668	2.535
E (J)	20.534	20.52

Table (10); Impact test results; M_2, V_2

Calculated terms	2024-T351 Aluminum alloy	Composite material
δ (mm)	2.2	37
P_m (N)	11.666	0.715
SEA (KJ/Kg)	23.332	2.383
E (J)	25.666	26.455

Table (11); Impact test results; M_2, V_3

Calculated terms	2024-T351 Aluminum alloy	Composite material
δ (mm)	2.8	47.1
P_m (N)	11.833	0.703
SEA (KJ/Kg)	23.667	2.345
E (J)	33.135	33.111

Table (12); Impact test results; M_3, V_1

Calculated terms	2024-T351 Aluminum alloy	Composite material
δ (mm)	2.7	40
P_m (N)	12.675	0.855
SEA (KJ/Kg)	25.351	2.852
E (J)	34.255	34.2

Table (13); Impact test results; M_3, V_2

Calculated terms	2024-T351 Aluminum alloy	Composite material
δ (mm)	3.7	54
P_m (N)	11.688	0.816
SEA (KJ/Kg)	23.376	2.722
E (J)	43.246	44.064

Table (14); Impact test results; M_3, V_3

Calculated terms	2024-T351 Aluminum alloy	Composite material
δ (mm)	4.8	70.1
P_m (N)	11.5	0.788
SEA (KJ/Kg)	23	2.627
E (J)	55.201	55.948

Figures (1) to (12) show the comparison in results between using 2024-T351 Aluminum alloy and the composite specimens for the same Impact conditions depending on the above tables..

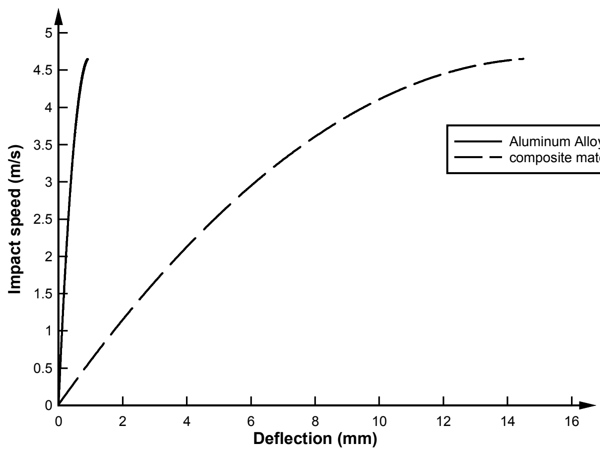

Fig. (1); comparison in deflection due to impact drop weight of (1Kg)

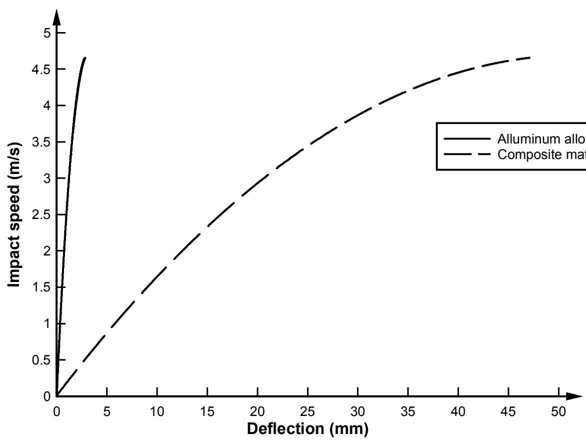

Fig. (2); comparison in deflection due to impact drop weight of (3Kg)

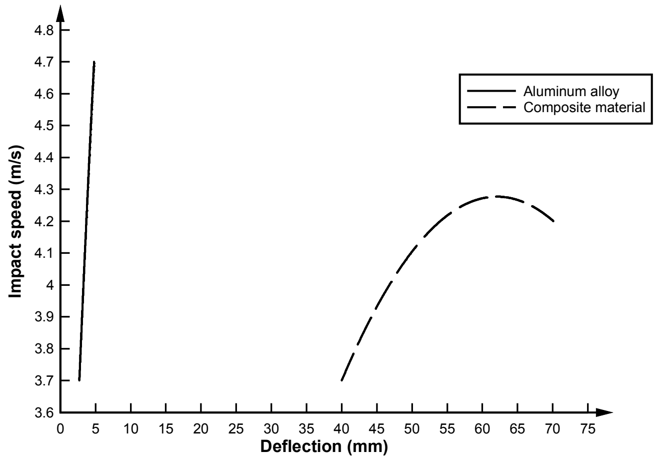

Fig. (3); comparison in deflection due to impact drop weight of (5Kg)

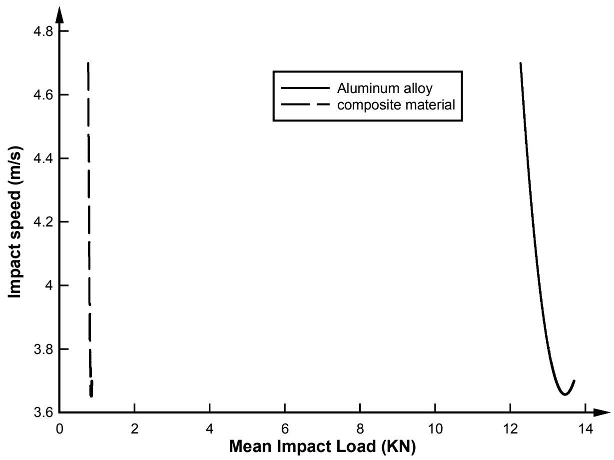

Fig. (4); comparison in mean crushing load due to impact drop weight of (1Kg)

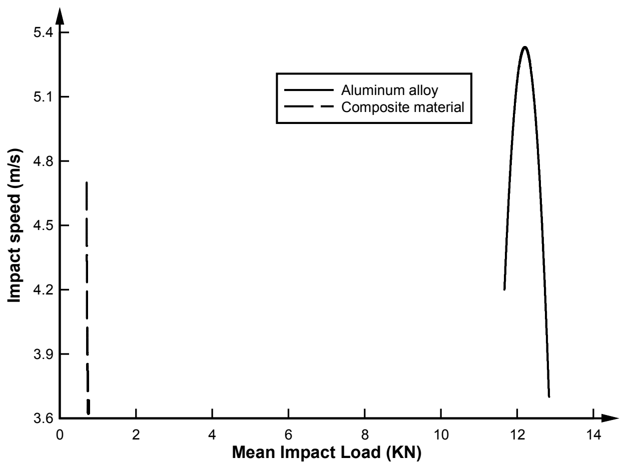

Fig. (5); comparison in mean crushing load due to impact drop weight of (3Kg)

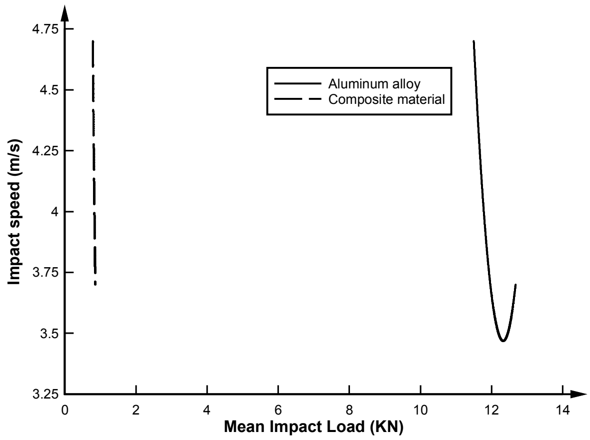

Fig. (6); comparison in mean crushing load due to impact drop weight of (5Kg)

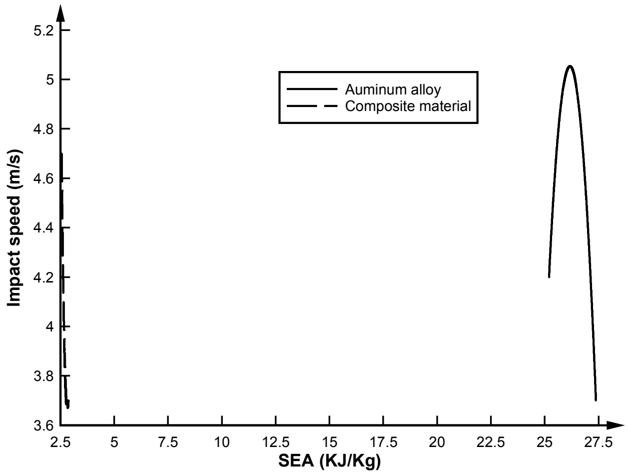

Fig. (7); comparison in specific energy absorption due to impact drop weight of (1Kg)

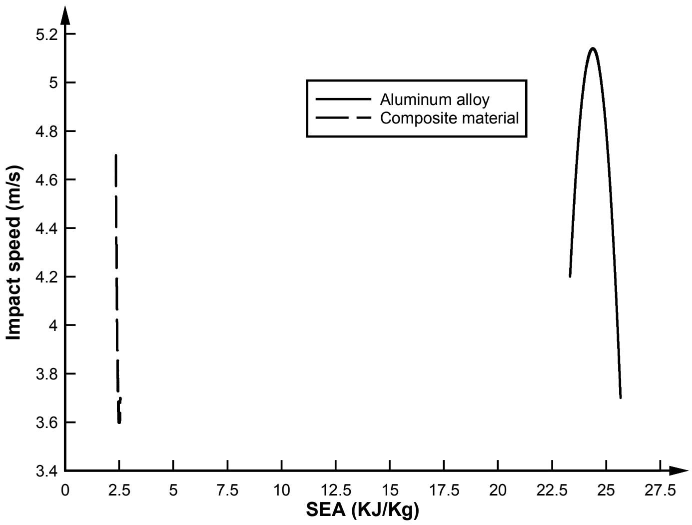

Fig. (8); comparison in specific energy absorption due to impact drop weight of (3Kg)

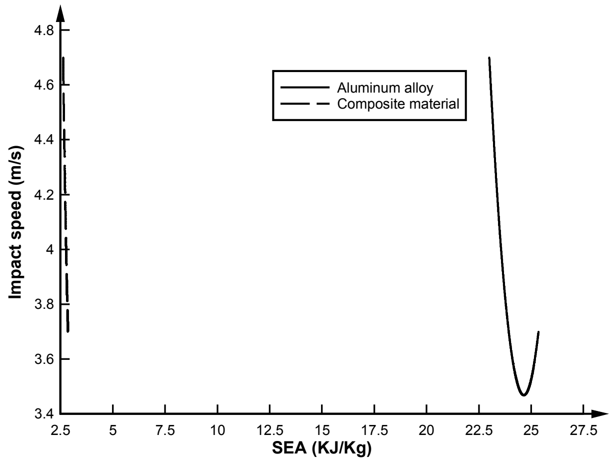

Fig. (9); comparison in specific energy absorption due to impact drop weight of (5Kg)

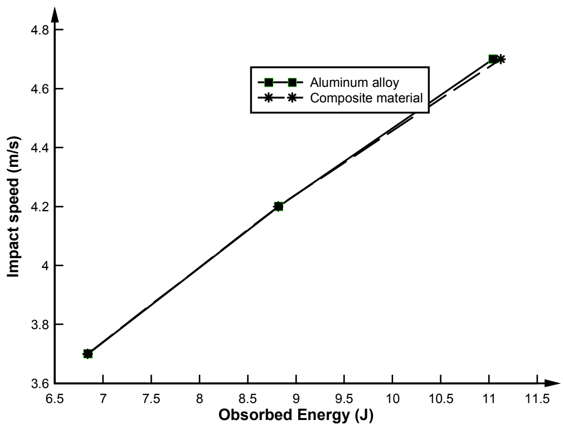

Fig. (10); comparison in absorbed energy due to impact drop weight of (1Kg)

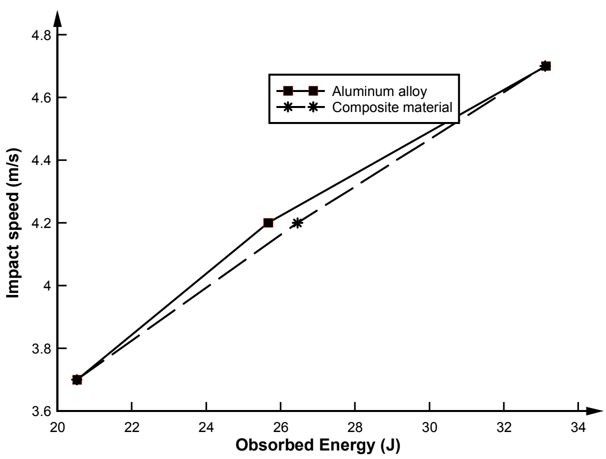

Fig. (11); comparison in absorbed energy due to impact drop weight of (3Kg)

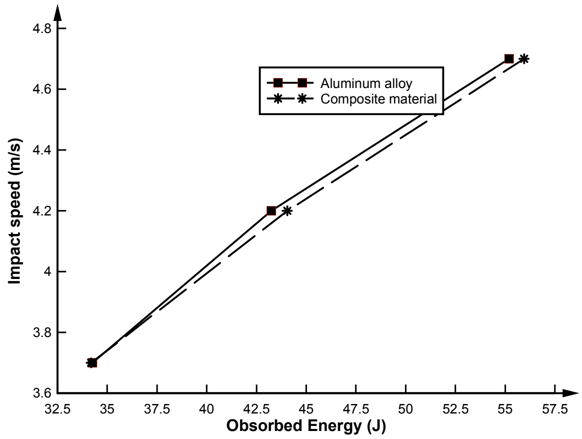

Fig. (12); comparison in absorbed energy due to impact drop weight of (5Kg)

Discussion:

This study does not concern with the relationships between the calculated parameters and the impact speed or weight, but it concerns with how they affect the difference in the calculated parameters values between the two selected materials. The increasing in impact speed and dropping weight caused a significant increase in deflection values and absorbed energy values, while the men crushing load and specific energy values showed disaffect among the variation in the drop weight and impact speed values, because they are related to the nature of the material. The deflection is affects linearly with increasing of drop weight and the impact speed, so the absorbed energy follows the deflection as shown in Eqn. (2).

It seemed that there is a large difference in deformation values, mean crush load, and specific energy absorbed between the two impacted materials at the same tests conditions of the 2024-T135 aluminum alloy and the composite material. But the absorbed energy values were the same for each material, so it depends on the mean impact load and the resulted deflection from impact. The mean impact load (crushing or collapse load) is defined as that load required to cause a significant permanent deformation of a particular section of the impacted body. The amount of deformation is not usually critical at the collapse load[12]. Therefore, the crushing load of cylindrical tube fluctuates with the proceeding of folding.

The behavior of the composite tube may be attributed to the fact that (0^o) fiber orientation produces an increased resistance to the initiation of progressive collapse, and the tube fails by global fracture. When the fiber orientation angle is increased, the resistance to the initiation of collapse is decreased, and the tube crushes progressively [13].

Conclusions:

1.Specimens made of composite materials are more deformed than those made of 2024-T135 aluminum alloy for the same impact conditions.
2.Increasing in drop weight or impact velocity causes increasing in the deflection.
3.The values of mean impact load and specific energy absorption were approximately constant for each material during different impact conditions.
4.The values of mean impact load and specific energy absorption of 2024-T135 aluminum alloy specimen were greater than those for composite material specimens at the same impact conditions.
5.For the industrial applications that depend on the amount of absorbed energy, the selection of composite material or 2024-T135 aluminum alloy will achieve the same target.

6. the specimen geometry and deformation mode play a major role in determining the energy absorption characteristics. The circular specimens tend to have higher specific energy absorption than the square specimen used by reference [3].
7. for the composite specimens, the SEA is less than that calculated by reference [3] when it used winding angle more than (45^o) and tube thickness more than (1.5mm).

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References:

1- Charoenphan, Saiphon, Bank, Lawrence, C. and Plesha, Michael E, "Progressive Tearing Failure in Pultruded Composite Material Tubes", *Composite Structure*, 63, pp 45-52, 2004.
2- Mahdi, E. Mokhtar, A. S., asari, N. A., Elfaki, F. and Abdullah, "Nonlinear Finite Element Analysis of Axially Crushed Cotton Fiber Composite Corrugated Tubes", *Composite Structures*, 75, pp-39-48, 2006.
3- Mohammad A. W., H. J. Al-alkawi, and Sameera A., *Buckling Mode Deformation of Composite Material Under Impact Loading at Elevated Temperatures*, Thesis; Ph.D University Of Technology, Iraq, 2009.
4- Ayad Arab K., *Low Speed Impact of Thin Walled Circular Tubes*, University of Al-Anbar, Iraq, Thesis; M. Sc 2005.
5- Eun-Ho Kima, In Lee, , Jin-Ho Roh, Jae-Sung Bae, Ik-Hyeon Choi, and Kyo-Nam Koo, "*Effects Of Shape Memory Alloys On Low Velocity Impact Characteristics Of Composite Plate*", Composite Structures, Volume 93, Issue 11, October 2011, Pages 2903–2909
6- Qing Hua Zhang, Bo Long Li, Xi Chen, Jia Ming Yin, Zuo Ren Nie, and Tie Yong Zuo, "*Characteristic Microstructure And Microstructure Evolution In Al–Cu–Mn Alloy Under Projectile Impact*", Materials Science and Engineering: A, Volume 531, 1 January 2012, Pages 12–17.
7- Hitech Industries Limited, *Technical Data Sheet*, Jebel Ali, U.A.E., 2007.
8- Lubin, G., *Hand book of Composites*, Van Nostrand Reinhold, USA, 1982.
9- ASTM, *Standard Test Method for Tensile Properties of Fiber-Resin Composites/D3039*, 1988.
10- ASTM, *Standard Test Method For Composite Properties Of Rigid Plastics/D695*, 1988.
11- Silcock, M., Hall, W., Fox, B., and Warrior, N., " Finite Element Modeling of Metallic Tabular Crash Structures with an explicit Code", *Int. J. Vehicle Safety*, Vol. 1, No. 4, 2006.
12- J. H. Ku, K.s. Eeo, S. W. Parkland Y.J. Kim, "Axial Crushing Behavior of the Intermittent Tack-Welded Cylindrical Tubes", *International Journal of Mechanical Sciences*, 43 (2001), p 521-542.
13- Thornton, P. H., J. J., and Beardmore, P., "Fiber-Reinforced Plastic Composites for Energy Absorption Purpose", *Composites science and technology*, Vol. 24, P 4, 1985.