Mechanics of Advanced Composite Structures 4 (2017) 207-210

Mechanics of Advanced Composite Structures

journal homepage: http://MACS. journals. semnan. ac. ir

Semnan University

Investigation into The Behavior of Nano-composite Tubes at Ballistic Impact

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PAPER INFO

Paper history:
Received 2016-10-23
Revised 2016-11-22
Accepted 2016-12-28

Keywords:
Composite cylindrical shell
Nanocomposite
Ballistic impact

DOI: 10.22075/MACS.2016.515

ABSTRACT

In this study, the behavior of filament wound nanocomposite tubes under transverse impact loading is investigated. Experimental specimens were manufactured using Epon 828 resin with 0.5, 1.5 and 3 weight percentages of nano silica. Because of the varying nanosilica weight percentages in the specimens, different behaviors were observed; increasing the weight percentage of nanoparticles increased impact strength. A ballistics test was performed with a gas gun, with projectile entry and exit speeds carefully recorded. All tests were carried out with projectiles with a mass of 9.3 grams at a speed of 130 meters per second. Failure of fiber, output velocity, damage area, and effects of varying percentages of nanoparticle content on resistance of the cylindrical shells under ballistic impact at various velocities are derived and presented. The final results are analyzed and compared.

1. Introduction

Composite materials have a higher strength–to–weight ratio than do metal and pure materials. This feature makes composite materials widely used in various industries, with composite pipes and pressure vessels playing a vital role, because they are highly corrosion–resistant. Therefore, composite pipes and pressure vessels have great utility in the oil, gas, fuel, and transportation industries. Due to the widespread use of these composite structures, it is important that they pass various trials from a security and safety standpoint. Among such trials, ballistics tests are of great import because of the risk of injury to humans in impact scenarios.

In 2010, Avila et al. [1] investigated the effect of a layered nanocomposite sandwich panel tested under impact load. They tested impact by two different parameters: 5 joules of energy and 75 joules of energy. Their results showed that by adding 5 wt% of nanoparticles, the amount of energy absorbed by the composite materials increases. Sevkatet al. [2] numerically and experimentally investigated the shaft torsional characteristics of composite under impact loading. They examined two types of shafts at different energy levels, recording force–time and energy–time for each test. They found that as impact energy increases, maximum torque and maximum angle of torsion drop. Koricho et al. [3], in 2015, investigated the behavior of composite materials modified with nano– and micro–materials under impact load. In their study, the composite was made of fiberglass, and impact tests were carried out at different energy levels. Their results showed that various combinations of nanoparticles increase composite performance against impact. The use of microparticles increased maximum power and reduced energy absorption, resulting in penetration. However, although the addition of nanoparticles to composite increases its energy absorption, the maximum power remained constant. Rostamiyan et al. [4], in 2015, studied the (wt%) of nanoparticles and fibers as independent parameters to determine their effects on impact strength. Varying weight percentages of nanoparticle were employed, as were differing fiber angles. The results show that nanocomposite with a 4.03 wt% has the highest impact and tensile strength, and the optimal nanoparticles percentage was found to be 6.4.

Matadi et al. [5] investigated response and damage of laminate composite under impact load. They manufactured two types of specimen with glass fiber/epoxy matrix and glass fiber/epoxy modified

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tri–block copolymer matrix. The impact results indicated that the addition of nanostrength leads to improved impact resistance and an increase in absorbed energy, especially at high impact. Ribeiro et al. [6] in 2015 experimentally tested composite cylinders built with wound carbon fiber filament undergoing side impact. Their results revealed that the effect of alignment layers and other factors, such as the thickness of the cylinder affected the type of damage, curve of the force, displacement and strain were plotted versus time in this study. Zhou et al. [7], in 2015, studied deformation and damage from impact on circular reinforced composite pipe to the numerical and experimental methods studied, recording load–time and transfers. Their results showed that more energy is absorbed by the amplifier is performed. As well as the failure of the hit show that has been a pure shear force.

In this study, nanosilica composite pipes with different percentages of nanosilica were examined.

2. Specimen Construction

To manufacture the composite samples, a filament winding device was used. The silica nanoparticles were uniformly mixed with epoxy EPON 828 resin and hardener EPIKURE F205. The materials were combined at a ratio of 1:0.58 to prepare the matrix material for the composite specimens. The silica nanoparticles were manufactured by the TECNAN Co. These silica particles were in powder form and had a density of 2400 kg/m^3. The nanoparticles were kept for 24 hours (h) at 70°C in order to extract humidity from the batch. Then, the silica nanoparticles were mixed with base material at 3,000 rpm for 90 minutes (min). The resulting mixture was heated and kept in an ultrasound device for 30 min. On completion of that step, the resulting compound was stirred at 3,000 rpm once more to complete the mixing process.

Next, the semi–automatic filament–winding device shown in Figure 1 was used to wrap filament, at a ±55 winding angle, around a polyethylene tube that is removed from the composite sample. While building a sample, the winding device sweeps fibers and spins the tube. At full build, 60 sweeps are done to the sample, which eventually reaches a thickness of 2 mm. Drying the resin can take up to 8 h. The samples were then cut to the desired length for testing.

3. Test Procedure

For ballistic tests, a gas–gun set up (Figure 2), which is available to mechanical engineering faculty at Tarbiat Modares University, was used. All tests are carried out using projectiles with a hemispherical nose. The projectile has a mass of 9.3 grams, a diameter of 10 mm and a length of 16.75 millimeters. A special fixture for holding the pipe was designed and constructed. This fixture, in turn, was attached to the main test machine and during the testing program, the fixture prevented jarring movements. All tests were performed with a projectile speed of 130 meters per second (m/s). To measure the amount of energy absorbed by the specimens, the input and output speed of the projectile, as measured by sensitive and accurate sensors.

4. Numerical Modeling

For a modeling fracture of composite materials, several standards and criteria exist. Among these criteria, the Hashin failure criterion [8] and the Puck failure criterion [9] have good accuracy; therefore, to predict and explain the behavior of composites, these criteria are used for this this paper. Modeling using ABAQUS/Explicit software was done. In this case, the composite pipes underwent 10–layer modeling with ±55 angles, and connections were completed. Similar to other experimental tests, the shape and speed of the projectile as well as the location of the object, were identical to that of the actual sample.

Figure 1. Filament winding apparatus

Figure 2. Gas gun

To apply the properties of the composite specimen and study it against ballistic failures, coding was done with a FORTRAN program, as a subroutine of ABAQUS / Explicit. The Hashin and Puck failure criteria for three – dimensional failure analysis of composite materials was written into the FORTRAN program.

5. Results and Discussions

The previous sections reviewed the manufacture and preparation of laboratory specimens. Also presented was the testing process, numerical modeling, and selection criteria. This section provides the experimental results and numerical data.

5.1. Standard tensile test

To obtain the mechanical properties of the matrix and fibers, standard tensile tests (ASTM D3039) were carried out. Standard tensile test results for fiber was the elastic modulus of 53.55 GPa, and tensile strength was 1550 MPa. It was observed that increasing the weight percentage of silica nanoparticles in the matrix increased the elastic modulus and maximum. Figure 3 displays elastic modulus increases corresponding to the increase in the weight percentage of nanoparticles.

5.2. Ballistics tests

As mentioned, ballistics tests were performed with a gas gun at a speed of 130 m/s. Table 1 presents the results of the projectiles' impact on composite tubes reinforced with silica nanoparticles. It can be seen that when the weight percentage of silica nanoparticles is increased, the output speed decreases, and the difference between the input and output speed increases. The pipes' thin–wall prevented the projectile from entering the sample. With this result, it can be stated that the projectile energy was spent on creating the damage to the pipes. Therefore, by increasing the difference between the input and output speed of the projectile, the energy transferred from the projectile to the pipe increased. The energy transferred from the projectile to the pipe was spent in creating the damage and failure in the pipe.

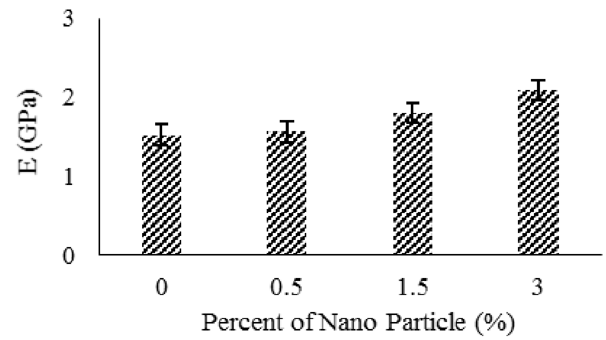

Figure 3. Elastic modulus by weight percentage of silica nanoparticles

Table 1. Experimental and numerical results on output speed

Input velocity (m/s)	Wt% of nanoparticles	Experimental exit velocity (m/s)	Numerical exit velocity (m/s)	% Difference
130	0	105	109	3.81
	0.5	99	108	9.09
	1.5	91	107	17.58
	3	85	104	22. 35

The difference between the results of experiments and numerical modeling is between 4% and 22%, as shown in Table 1. This difference is due to some experimental parameters that were not included in the numerical modeling One such parameter was the friction force between the pipe and projectile, which was not included due to the tube thinness. In addition, laboratory errors can cause this discrepancy. The energy absorbed by the tube is shown in Table 2. It is seen that with increasing the weight percentage of nanoparticles, the absorbed energy increases.

Energy is absorbed by the tube, causing the failure and damaging it. Is expected to increase the amount of energy absorbed, damage and area of failure will increase. Figure 4 shows the area of failure of the samples with 0%, 0.5%, 1.5%, and 3% silica nanoparticles.

The failure area shape was similar in all samples tested. Figure 5 shows tubes with 0.5 wt% silica nanoparticles. As can be seen, the area of failure formed a circle in the center of the penetration and grew in the direction of the fiber. Cracks and failures in the matrix and fiber rupture are the most important failure models observed in the pipes.

Table 2. Energy absorbed by the tubes

Input velocity (m/s)	Wt percentage of nanoparticles	Experimental Energy absorption (J)	Numerical Energy absorption (J)
130	0	27.31875	23.33835
	0.5	33.01035	24.3474
	1.5	40.07835	25.34715
	3	44.98875	28.2906

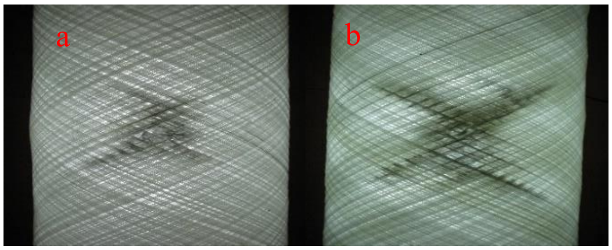

Figure 4. a) Sample with 0wt% nanoparticles; b) Sample with 3wt% nanoparticles.

Figure 6. Tube with 0.5 wt% nanoparticles

6. Conclusions

According to the expression, it was observed that the addition of silica nanoparticles caused the elastic modulus and the composite strength to increase. The ballistics tests provided information about the composite pipe's resistance against ballistic impact. It was observed that increasing the weight percentage of silica nanoparticles in the tube increases its resistance to the projectile by 30%, while increasing energy absorption and expanding of the area of failure. A comparison of the experimental results with the numerical data shows that there is good agreement between them. In the end, it can be stated that the addition of 3 wt% silica nanoparticles to the matrix composite can increase resistance against impact.

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