

# Composite Pressure Vessels and Nozzles

Sajini Mary Philip  
Department of Civil Engineering,  
Younus College of Engeneering And Technology,  
Kollam, Kerala.

Raji R.  
Department of Civil Engineering,  
Younus College of Engeneering And Technology,  
Kollam, Kerala.

**Abstract**— A composite material is a combination of two or more materials that results in better properties than individual component used alone. Pressure vessel and nozzle shows better performance as composite one than materials with isotropic properties. The usage of multilayer composites decreases the weight as well as the material cost required to manufacture.

**Keywords**— Pressure vessels; nozzle; Composite; Isotpic.

## I. INTRODUCTION

### A. Composites

A composite material is a combination of more materials that results in better properties. Reinforcement and matrix are the two constituents. Reinforcing phase provides strength and stiffness, in some case which is harder than matrix. Reinforcement is usually a fibre or a particulate. Particulate have dimensions that are approximately equal in all directions and which are spherical, platelets, or any other regular or irregular geometry. Particulate composites tend to be much weaker and less stiffer, but they are usually much less expensive than continuous fibre composites. A fibre has a length that is much greater than its diameter. The length-to-diameter (l/d) ratio is known as the aspect ratio and can vary greatly. Continuous fibers have long aspect ratios, while discontinuous fibers have short aspect ratios. Continuous-fiber have a preferred orientation an discontinuous fibers generally have a random orientation. examples of continuous reinforcements include unidirectional, woven cloth, and helical winding (Fig 1. a), while examples of discontinuous reinforcements are chopped fibers and random mat (Fig 1. b).

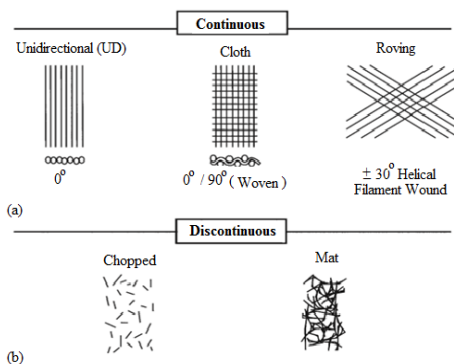


Fig 1. Typical reinforcement types

In composites, materials can be classified as either isotropic or anisotropic. Isotropic materials have the same material properties in all directions, normal loads create only normal strains and the properties are independent of direction within the material. But in anisotropic materials, which have different material properties in all directions at a point in the

body. Subclass of anisotropic material is classified as orthotropic. Orthotropic materials have properties that are different in three mutually perpendicular directions and three mutually perpendicular axes of symmetry. Such that load applied parallel to these axes produces only normal strains. However, loads produces both normal and shear strains. Therefore, orthotropic mechanical property depends on orientation.

### B. Pressure vessels

Pressure vessels are containers or reservoirs for the containment of pressure, which are subjected to pressure internal or external substantially different from the ambient pressure. Pressure vessels and associated equipments are used in oil, space, chemical, nuclear power and many other industries.

### C. Nozzle

Nozzle is a part that is seen in rockets, high pressure exhausted in nozzles that creates thrust which pushes a vehicle forward. High temperature, high pressure combustion gases are discharged through the converging-diverging nozzle. By this way, chemical energy of the propellant is converted to kinetic energy and thrust is obtained. The geometry of the nozzle directly determines how much of the total energy is converted to kinetic energy. Therefore nozzle design has a very important role on the performance of a rocket motor.

## II. EXPERIMENTAL AND NUMERICAL INVESTIGATIONS

Analysis of nozzle, pressure vessel and composite material behavior has been studied by several investigators using numerical as well as experimental techniques. Numerical investigations were carried out using Finite Element Method. The relevant literature pertaining to the present study has been reviewed.

Sreelakshmi and Pany (2016) carried out FEA on cylindrical and spherical pressure vessels having mismatch/sinkage in the circumferential/longitudinal joint, with equal and unequal shell thickness/radius on either side of the joint. Vessel material used is 15CDV6. For cylindrical and spherical shell with different mismatch, stress factors are compared and deformations and elastic stress distribution along meridional distance is graphically presented for different thickness ratio. The results obtained from the analysis showed good agreement with the experimentally obtained results. Analyses were carried out using ANSYS.

Suvarna and Ravisekhar (2016) analyzed the components of multilayered high pressure vessels, their advantages over mono block vessel. E glass epoxy and S2 glass epoxy materials were used in the multilayer pressure vessel. The usage of multilayer pressure vessel decreased the weight as well as the material cost required to manufacture. The vessels are favored to work under conditions of high temperature and high pressures. The usage of multilayer pressure vessels had more advantages than single wall pressure vessels. The use of composite material S2 glass epoxy and E glass epoxy in place of steel, decreased the overall weight of multilayered vessels. The usage of E glass epoxy and S2 glass epoxy is safe since stress value is less.

Senthil *et al.* (2014) investigated the structural response of debonded carbon fibre reinforced polymer splice joint subjected to compressive load. It was found that debonds have major importance for the behavior of carbon fibre reinforced polymer. Although the compressive behavior was similar to that of nominal splice joint, the stiffness was considerably decreased in the presence of debond, and also the load carrying capacity was reduced by 17% approximately. The experimental results were compared with the analytical predictions and numerical simulations using Rayleigh–Ritz method and finite element method. Analyses were carried out using ANSYS. Both the experimental and numerical simulations were almost same.

Nayak *et al.* (2014) investigated problems with the present generation composites and prospects for further developments. The applications of composites as structural materials showed a significant growth in usage. The nature of composite materials behavior and special problems in designing and working with them are then highlighted. The issues considered were the impact damage and damage tolerance in general, environmental degradation and long-term durability. Important requirements of an aerospace structure and their effects on the design are discussed. Simulation was undertaken in framework of ABAQUS commercial finite element package. Predicted mechanical properties as well as experimental results were compared. Composite materials offered high fatigue and corrosion resistance. Also, due to the high strength to weight ratio, they are found to be best suited for various aerospace applications.

Liu *et al.* (2014) conducted a detailed study about composites. Composites have been increasingly employed in various fields including the airplane, fuel cell vehicle, communication power systems and electricity generation. Improved weight savings, increased fuel efficiency, enhanced durability, and superior structural properties make composite materials ideal for aerospace applications. In general, the carbon fibre composites are used to manufacture the laminated composites by deploying the carbon fibres in several unidirectional layers and all fibres have a common orientation in each layer, and these layers are stacked in angled orientations to achieve high stiffness and strength in different directions. Since the stiffness and strength of an individual layer are much higher in the fibre direction than in the transverse direction, the designable composite layers

sufficiently bring the mechanical performance in the carbon fibre principal orientations into play in order to suit the anticipated load bearing distributions.

Urade *et al.* (2014) carried out the stress analysis of multi-layer pressure vessel made of a homogeneous and isotropic material and subjected to internal pressure. Both theoretical and FE results were compared and effect of multi-layering on stresses induced and the volume requirement to sustain the given pressure is calculated. The hoop stresses decreased with increase in number of layers.

Dhanya (2014) analyzed a steel-steel, aluminium-aluminium and steel-aluminium compound cylinders keeping inner diameter, outer diameter and material as constant and varying the interfaces. Optimum interfaces were obtained such that inner diameter of both cylinders experiences the same amount of effective stress which is equal to yield stress of material. Burst pressure of optimum cylinder was also studied. Mass of steel-aluminium compound cylinder was less compared to equivalent steel cylinder. The reduction of mass was more at higher pressure.

Patil and Bajpai (2014) conducted numerical and experimental investigations on different pressure vessel elements such as shell, torispherical head, toriconical bottom, operating nozzle, its reinforcement. The interference between the vessel and welding was analyzed to understand effects on stress attributes of the vessel. Stress obtained experimentally was found to be very close with the numerical result. Maximum stress was found near to the shell flange and head flange, hence some portion of shell and head weakens over the period of time.

Chankapoe *et al.* (2013) investigated the performance and key design parameters of rocket. The nozzle throat erosion in solid rocket motors was predicted according to the thrust profile of motor in operating conditions and a model for optimum performance of rocket was also developed. Change in throat radius and thrust coefficient was used for adjusting the ideal performance of conical nozzles. Pressure and thrust data acquired from the tests were analyzed to determine the instantaneous nozzle throat diameter variation. Correlation comparing measured erosion rate data showed agreement within 1.6 mm/s and nozzle thrust coefficient loss was found approximately 24% from nozzle throat erosion during burning.

Xiaoying (2011) simulated the temperature distribution on the rocket nozzle wall in high temperature environment, which is most important for assessing safety and reliability of the nozzle. The coupling simulation of heat transfer and transient temperature of the rocket nozzle wall was carried out. Net radiation computing method was used to analyse radiative transfer between the plume and nozzle wall. A differential was established equation for two-dimensional transient conduction in the cylindrical coordinate. The convection and radiation heat fluxes, the transient temperature along the wall length and thickness of the composite nozzle wall after startup of the engine were

investigated. The study was conducted on the nozzle of an experimental rocket engine, one fabricated with stainless substrate and other with multi-layer composite materials. Transient temperature increased in both internal and outside walls of the rocket nozzle with time when rocket engine starts. On the same section, the temperature decreased along the thickness from internal to outside of the wall.

Shimizu *et al.* (2008) investigated flow structures inside and outside a rocket nozzle which were indispensable for actual development of rocket engine. One is transition of the flow structure between free shock separation and restricted shock separation inside a nozzle which generates side-load sometimes, another one is ignition over pressure induced by engine ignition. Over pressure, which originates in shock wave, imposes a vortex ring generated and propagated from the nozzles. Interaction between over pressure waves and vortex rings made the force acting on nozzle asymmetric.

Thakre and Yang (2008) studied the chemical erosion of carbon-carbon/graphite nozzle materials in solid rocket motors at practical operating conditions. Both metalized and non-metalized AP/HTPB composite propellants were treated. The erosion rate followed the trend exhibited by the heat flux distribution and it was most severe in the throat region. The erosion rate increased with increasing chamber pressure, mainly due to higher convective heat transfer and enhanced heterogeneous surface reactions. For non-metalized propellants, the recession rate was dictated by heterogeneous chemical kinetics because the nozzle surface temperature was relatively low. For metalized propellants, the process was diffusion controlled due to the high surface temperature. The erosion rate decreased with increasing aluminum content, a phenomenon resulting from reduced concentrations of oxidizing species  $H_2O$ ,  $OH$ , and  $CO_2$ . The transition from the kinetics-controlled to diffusion-controlled mechanism occurred at surface temperature.

Park and Kang (2002) investigated thermal and ablative properties of Phenol Formaldehyde (PF) resin composites reinforced with carbon fibres heat treated at low temperature. Low Temperature Carbon Fibres (LTCF) were obtained by a continuous carbonization process from stabilized *Poly Acrylo Nitrile* (PAN) fibres. The properties of LTCF reinforced PF (LTCF-PF) composites were compared with those of High Temperature Carbon Fibre (HTCF) reinforced PF (HTCF-PF) composites. The thermal conductivity of the LTCF-PF composite was lower than that of HTCF-PF composite by about 35% and 10% along the directions parallel and perpendicular to the laminar plane, respectively. The erosion rate was higher by about 30% in comparison with HTCF-PF composite. The result suggests that use of LTCFs as reinforcement in a composite may improve the thermal insulation of the composite but will decrease the ablative resistance.

Patton *et al.* (2001) evaluated mechanical and thermal properties of vapor grown carbon fibre/phenolic matrix composite to know the potential of the material in solid

rocket motor nozzles. Composite specimens with varying VGCP loading including one sample with x-ray on carbon fibre plies were prepared and exposed to heat flux under plasma torch. The specimens had low erosion rates and a little char formation, conforming that these materials were promising for rocket motor nozzles i.e., VGCF composites have low thermal conductivity.

Lacoste *et al.* (1999) investigated the carbon-carbon extendible nozzles and found that C-C composite materials can be used to lighten architectures of propulsion systems, which have high specific mechanical properties and thermal characteristics. C-C thermo structural composite materials were used for extreme operating conditions of large rocket engines to improve their performances. When the C-C nozzle was attached to the engine, the nozzle diameter increased, which provided an expansion ratio and increased impulse to the engine.

Carlson (1980) developed an empirical expression for the drag coefficient of a spherical particle in flow regimes in solid propellant rocket exhausts. Heat-transfer relationships were applied to the gas particle nozzle flow case. The effects of these relationships on computed particle velocities and temperatures were studied. It was found that inertial and compressibility effects dominate for large particles and high chamber pressures, causing the thermal and velocity lags to be less than those predicted under a Stokes flow assumption. However, for small particles and low chamber pressures, rarefaction effects dominate, and the Stokes flow assumption leads to low estimates of particle lag.

#### A. Abbreviations

C-C	Carbon-Carbon
HTCF	High Temperature Carbon Fibre
HTS	High Temperature Superconductors
LTCF	Low Temperature Carbon Fibre
PF	Phenol Formaldehyde
VGCF	Vapour Grown Carbon Fibre
VGCP	Vapour Grown Carbon Phenolic

#### III. CONCLUSION

From above mentioned works we can conclude that

- Composite pressure vessels and nozzles have more advantages than isotropic materials.
- The cost of composite material is comparatively higher than that of isotropic one, although in the case of weight reduction; load carrying capacity etc. composite materials shows more efficiency.
- Carbon – carbon composites are more validly used in lighten architectures of propulsion systems.
- Carbon fibres anticipates load-bearing distributions.
- Composite with more layers are more preferable.
- Bidirectional composite have more advantage over unidirectional one.

- vii. the usage of multilayer pressure vessel and nozzles decreases the weight as well as the material cost required to manufacture.
- viii. Work under conditions of high temperature and high pressures. The usage of multilayer pressure vessels is having more advantages than single wall pressure vessels.
- ix. During temperature loading the temperature decreased along the thickness from internal to outside of the wall for a composite material.

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