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Review on Delamination and its effects in GFRP Composites

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Abstract — *Glass Fiber Reinforced Plastics (GFRPs) are the newer process materials for modern high technology products which are finding commercial applications considerably in recent time. The combination of different materials glass fiber and polymer matrix having dissimilar mechanical properties causes a problem in processing due to their heterogeneous structures. GFRP parts are generally assembled together by fastening, which requires drilling hole a common machining process in these parts. Delamination of the GFRP parts is a critical defect because more than 50 percent of rejection of parts occurs due to delamination, so it is important to understand the delamination behaviour. It is seen at the entry and exit of the hole during any machining process. Different parameters and techniques to control the delamination are discussed in this paper in special reference to GFRP composites.*

Keywords – *GFRP, Delamination, Peel-up delamination, Peel-out delamination, Machining.*

INTRODUCTION

Glass Fiber Reinforced Plastics (GFRPs) consist of glass fibers of high strength and modulus embedded in or bonded to a polymer matrix. In this form, both fibers and matrix retain their identical physical and chemical properties; still they produce a combination of properties that cannot be achieved individually. Generally, fibers are the main load-carrying members and the matrix surrounded the fibers keeps them in the desired location and orientation as well as acts as a load transfer medium and protects them from environmental damages due to elevated temperatures and humidity [1]. In present days engineering products, development and application of Fiber Reinforced Plastics (FRPs) increased at fast speed. The idea of composite is not new; its application was found in ancient time also. Fiber Reinforced Plastics are basically composites which are the materials composed of two or more distinctly identifiable material constituents. Fiber Reinforced Plastic (FRP) have been widely used in engineering application such as transportation industries, power generation equipment, automotive, aircraft and manufacture of spaceships and boats due to their significant advantages over other materials. These are an economical alternative to stainless steel and other materials in highly corrosive industrial applications. They provide high specific strength/stiffness, superior corrosion resistance, light weight construction, low thermal conductivity, and high fatigue strength, ability to char and resistance to chemical and microbiological attacks. As a result of the widening range of applications of these materials, its study has become a very important subject for research [2, 3].

Glass Fiber Reinforced Plastics (GFRPs)

The fibers used as reinforcements are glass fibers, carbon fibers, and aramid fibers. In GFRP, glass fibers are used as reinforcements. They are further classified into many types as A glass, C glass, D glass, E glass AR glass R glass, S glass according to their specific properties like abrasion resistance, dielectric strength, alkali resistance and high tensile strength and modulus. Glass fibers has advantages as low cost, easy manufacturing, comparatively good stiffness and strength value in addition to low density, better chemically resistance and electrically insulation properties. One of the limitations of GFRP is that when it is subjected to high tensile load, they are prone to break. However, they remain break resistant when subjected to high tensile load in short time frame. For different application requirement various forms of glass fibers are used such as chopped-strand mat, continuous mat, fiber glass roving, woven roving and yarns, surface mat [4]. The matrix comprised organic, polyester, thrmostable, vinylester, phenolic and epoxy resins [14]. GFRP composites has wide range of applications, they are used in fairings, passenger compartments, storage room doors, pipes, tanks, pressure vessels, door and elevators of aircraft due to their high mechanical properties [4, 5].

Manufacturing Processes used in GFRP

As the fields of application expand, the use of various types of machining has increased in GFRP fabrication. For the machining of GFRP generally following manufacturing processes are used.

- Drilling
- Milling
- Turning
- Water Jet Machining (with or without Abrasives)
- Laser Beam Machining
- Ultrasonic Machining

Drilling is probably the machining process most broadly applied to composites since components made out of composite materials are usually near net shaped, thus requiring holes for assembly integration. Several non-traditional machining processes such as laser cutting, water-jet cutting, ultrasonic cutting etc., have been developed for machining holes in Polymer Matrix Composites. Due to anisotropic and inhomogeneous structure of Polymer Matrix Composites, drilling cause some problems, which do not occur in other materials. However, the glass fibre constituent often makes it difficult the machining of GFRP. Machining of composite materials requires a better understanding of cutting processes to achieve accuracy and efficiency [6]. As structural materials, joining of GFRP laminates to other metal materials structures or GFRP parts could not be avoided [7], and bolt joining efficiency and quality critically depend on the quality of machined holes. Various drilling processes are extensively used for producing riveted and bolted joints during assembly operation of composite laminates with other components. For rivets and bolted joints, damaged-free and precise holes must be drilled in the components to ensure high joint strength and precision. However, some special characteristics of composite laminates such as non-homogeneous, anisotropic, and highly abrasive and hard reinforced fibers, result in them difficult to machine [8, 9]

Delamination

Among the defects caused by drilling, delamination around the drill hole site appears to be the most critical, delamination can often become a limiting factor in the use of GFRP for structural applications [10]. Delamination is reducing the structural integrity of the material, it also leads to poor assembly tolerances and it has the potential for long-term performance deterioration.

Delamination mechanisms

There are two delamination mechanisms associated while machining GFRP. These are known as peel-up delamination which occurs at the drill entrance, initial laminae being taken up along the drill flute as the drill enters the laminae and upper laminae being pulled up from the uncut portion of the job resulting in peel-up delamination. Push-out delamination which occurs at the drill exit as the drill reaches the exit side of the material near the lowest layers of the laminate, the laminae under the drill is compressed and thrust of the drill pushes out the laminae from the hole as it overcomes the interlaminar bond strength [15, 16].

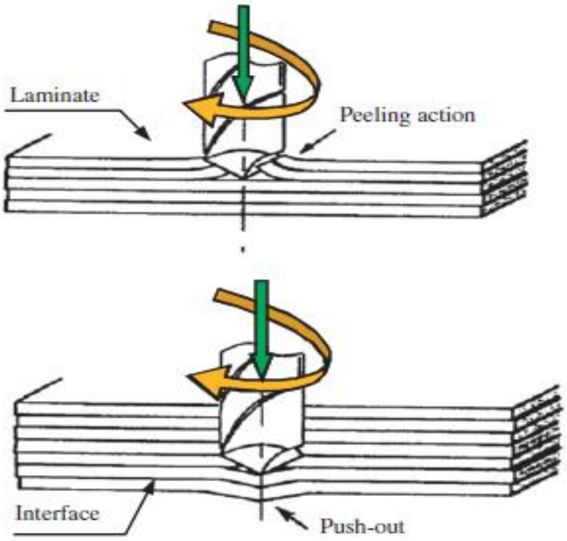

Fig. 1 Peel-up delamination at entrance and Push-out delamination at exit.

Assessment of delamination

There are various ways to measure the delamination which vary from one researcher to another. Some consider measurements of delaminated area or crack length, others use ratios of delaminated areas or radii to reference areas or radii as the delamination assessment [17]. Following are the various measures of delamination assessment [17].

- Delamination factor (F_d)
- Delamination size
- Two-dimensional delamination factor (F_a)
- Damage ratio (D_{rat})
- Delamination factor (F_d)
- Adjusted delamination factor (F_{da})
- Equivalent delamination factor (F_{ed})
- Refined delamination factor (F_{DR})
- Shape circularity (f)
- Minimum delamination factor (Fd_{min})

Some important definitions are as follows:

Delamination factor (F_d)

The conventional delamination measure for assessment and comparison of the delamination damage due to drilling of composite laminates is the one proposed by Chen [13]. It is a ratio called delamination factor (F_d) and he defines it as the ratio of the maximum diameter of delamination (D_{max}) to the nominal diameter of drilled hole (D) as shown in Figure 2 [9, 13].

$F_d = D_{max} / D$

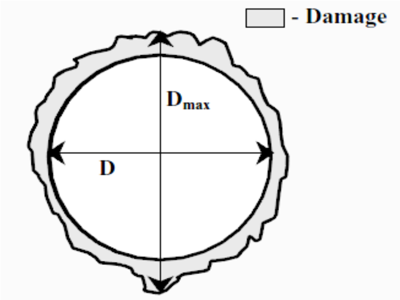

Fig. 2 Delamination damage [11].

Delamination size

It is the delamination measure proposed by Khashaba et al. It is defined as the difference between the maximum radius of the damaged area (R_{max}) and the radius of the drilled hole (R) as shown in the Figure 3 [17, 18].

Delamination size $= R_{max} - R$

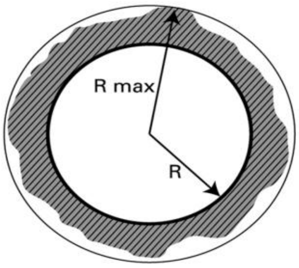

Fig. 3 Delamination damage [17, 18].

Damage ratio (D_{RAT})

It is defined as the ratio of the damaged area at hole periphery (D_{MAR}) to nominal area of drilled hole (A_{AVG}) [19].

$D_{RAT} = D_{MAR} / A_{AVG}$

Delamination Factor (F_d)

The delamination factor (F_d) is calculated as the ratio of the area of delamination (A_d) to the nominal area (A) [20].

$F_d = A_d / A$

The literature survey shows that different authors have used varying approaches to quantify the delamination factor (F_d) and there is no consistency and agreement among the various methods [17].

Assessment methods for delamination

There are many techniques developed for assessing the delamination which includes the measurement of dimensions like diameter and area. Earlier more focus was given on the maximum diameter of delamination damage, later it is understood that consideration of damaged area was more appropriate in assessment of delamination [17, 21, 22]. The methods for the assessment of delamination are as Microscopy, Image processing, Acoustic emission, Ultrasonic C-scan, Interferrometry, Radiography and X-ray computerized tomography.

Measures to control delamination

For controlling delamination, different measures are taken. Drilling is most widely used technique for making hole in GFRP. Different variant of drilling process used for machining the holes in GFRP materials are as Conventional Drilling, High Speed Drilling, Vibration Assisted Drilling and Ultrasonic Assisted Drilling.

- In conventional machining feed rate, tool material and cutting speed are the most influential factor on the delamination hence machining at higher speed, harder tool material and lower feed rate have lesser delamination of the GFRP.
- High Speed Machining is suitable for drilling GFRP ensuring low damage levels and have higher productivity and lower production cost.

- Vibration Assisted Drilling and Ultrasonic Assisted Drilling have lesser thrust hence lesser delamination compared to conventional drilling, which indicate that both Vibration Assisted Drilling and Ultrasonic Assisted Drilling are more appropriate and have better result compared to conventional drilling of GFRP.

CONCLUSIONS

The field of application of GFRP expands because of their better mechanical and chemical properties. Delamination is a common problem occurring in various cutting processes; it results in varying shape and size with cracks in matrix material surrounding the hole. It is found that delamination is the major defect as more than 50 percent rejection of parts occurs due to delamination. It also results in poor assembly tolerance and has the potential for long term performance in addition to the structural integrity of GFRPs. While drilling a hole parameters such as feed rate, thrust force and spindle speed are important and they need to be optimized. High Speed Machining, Vibration assisted drilling and Ultrasonic assisted drilling has scope for future work on drilling of GFRP.

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