Composite Structures 93 (2011) 759–766

Contents lists available at ScienceDirect

Composite Structures

journal homepage: www.elsevier.com/locate/compstruct

Joint performance of the glass fiber reinforced polypropylene leaf spring

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ARTICLE INFO

Article history:
Available online 10 August 2010

Keywords:
Leaf spring
Fiber reinforced polypropylene
Bolted joint
Fatigue
Failure

ABSTRACT

Commercial utilization of the composite leaf springs in the suspension application is significantly decided by its eye end joint performance. Present work attempts to design and evaluate the performance of double bolted end joint for thermoplastic composite leaf spring. Injection molded 20% glass fiber reinforced polypropylene leaf springs were considered for the joint strength evaluation. Servo hydraulic test facility is utilized to evaluate the static and fatigue performance of the bolted joint. Various bolt sizes were utilized for the joint and its performances were evaluated under static loading condition to understand the effect of fit between bolt and its hole of the joints. Ultimate bearing strength of the joint is found to decrease with the increase in the clearance between bolt and part hole. Joints were subjected to various amplitudes of completely reversed fatigue loads to evaluate the endurance strength. Load–deflection hysteresis plot of the joint under fatigue conditions is continuously measured and used as the bearing damage index of the joint. Inspection of the bearing surface tested under static and fatigue loading condition revealed severe matrix deformation and fibrillation. In spite of unidirectional load being acted at the joint, curved nature of the bearing surface induces bi-axial stresses, which results in severe matrix fibrillation at the bearing surface. Failure morphology under static conditions shows net-tension beside the bearing damage. Failure morphology under fatigue condition revealed net-tension, and shear-out failures besides the bearing damages.

1. Introduction

Leaf spring made of glass fiber-reinforced plastics provides improved fuel efficiency as well as comfortable level of riding. Excellent fatigue life and corrosion resistance feature of the glass fiber reinforced composite leaf springs contribute to replace steel leaf spring for the suspension applications. In the last two decades, extensive investigations have been carried out on the design and development aspects of thermoset leaf springs [1–10]. Composite leaf springs made from glass reinforced epoxy resin for automobile suspension is investigated by Beardmore and Johnson [1] and Beardmore [2]. Daughtery [3] utilized composite leaf springs for heavy truck application and reported the performance. Hou et al. [4] developed glass fiber reinforced polyester leaf spring for railway wagon application and studied the transient response by using a shaker test rig. Design, development and performance evaluation of epoxy reinforced glass fiber leaf spring is reported by Morris [5]. Hand lay-up vacuum bag process was utilized by Al-Qureshi [6] for fabricating a single leaf with variable thickness using fiber glass epoxy resin. Sancaktar and Gratton [7] explored the capabilities of composite leaf springs made out of unidirectional E-glass reinforced epoxy resin for light weight application. Lo et al. [8] developed constant width, variable thickness glass fiber reinforced epoxy leaf spring by compression molding and utilized for tank trailer application. Shankar and Vijayarangan [9] reported a low cost fabrication technique of epoxy glass fiber leaf spring and reported significant weight savings compared to that of steel leaf spring. In order to utilize composite leaf springs in the commercially viable suspension system, the joint strength between leaf spring and eye end must have superior strength than that of the designed leaf spring [10]. Bolted joints and adhesively bonded joints are commonly being utilized for joining the composite structures. Bolted joints were found to be more useful than adhesive bonded joints, due to the superior load transfer and less sensitive to the surface preparation characteristics [11]. The potential site of stress concentration in the joint region determines the strength of a structure. Thoppul et al. [12] reported an extensive review work on mechanical joints of polymer composite parts, wherein, tension, shear, bearing, cleavage and pull-through were reported as most commonly observed failure modes. Many experimental investigations on the performance of composite pinned joints under static and dynamic condition have been carried out in the recent years [13–26]. Collings [13] investigated the influence of geometric parameters *viz.* width, hole diameter, end distance and thickness on the joint strength. In addition it is reported that the bearing strength of carbon fiber-reinforced plastics could be improved by increasing the lateral compressive stress around the

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doi:10.1016/j.compstruct.2010.07.015

Nomenclature

B	bearing failure	ε_b	bearing strain
d	hole diameter	δ_p	fastener displacement
N	net-tension failure	σ_b	bearing stress
P	maximum applied load	(Δ_N)	hole elongation
S	shear-out failure	(δ_i)	fastener translation
t	thickness of the composite plate	(δ_N)	fastener translation after N fatigue cycles
UTS	ultimate tensile strength		

loaded hole. Kretsis and Matthews [14] observed the change in failure mode from bearing to tension when the specimen width decreases for the glass fiber reinforced epoxy laminates. Stockdale and Matthews [15] investigated the effect of clamping pressure on bolt bearing loads on glass fiber epoxy polymer parts. Higher clamping force found to prevent the delamination and improved joint strength. Pakdil et al. [16] reported the change in failure mode of glass fiber epoxy laminated plate for various clamping torque. Cooper and Turvey [17] studied the influence of bolt clamping force on stiffness and failure mode of part made of pultruded glass fiber reinforced polyester resin. McCarthy et al. [18] investigated the bolt–hole clearance effect on single bolted, single lap carbon fiber epoxy joint and reported the reduction in joint stiffness due to the increase in clearance. Crews [19] reported the improved static and fatigue limit of graphite-epoxy laminate with high clamping torque and discussed the influence of water in degrading the static and fatigue strength. Chen [20] carried out static and fatigue testing on graphite/epoxy laminate under hygrothermal cycling and characterized the hole elongation pattern. Deteriorating joint strength due to the increase in moisture content is reported. Lim et al. [21] evaluated fatigue characteristics of the bolted joints for the unidirectional satin woven glass fiber epoxy laminate. It is found that the composite laminate whose major plies are stacked in the axial direction with appropriate clamping pressure would improve bolted joint strength. Camanho and Matthews [22] obtained a good agreement between experimental and numerical prediction in joint performance of carbon fiber-reinforced plastics. Godwin et al. [23] used glass fiber reinforced polyester material for multi-bolt joints and reported the pitch as an important geometric parameter in deciding the strength of bolted joints. The influence of traction forces by two parallel rigid pin for two parallel circular holes in woven glass fiber–vinylester were studied by Karakuzu et al. [24] and reported the influence of end distance in deciding the failure mode. Okutan [25] investigated the failure of E-glass epoxy laminate with pinned joints with the aid of numerical and experimental techniques. It is reported that the lay-up played an influencing role on the mode of failure. Atkas et al. [26] observed good agreement between experimental and numerical predictions of performance of glass–epoxy laminate. Very few works has been reported on joint strength performance of composite leaf spring. Hou et al. [27] designed three types of eye end attachment for the leaf spring and evaluated the static and dynamic performance of developed glass fiber reinforced polyester eye end. Local delamination was reported as the main failure for the developed leaf spring eye end. Shokrieh and Rezai [28] proposed four different types of end joints for the glass/epoxy leaf springs and highlighted the manufacturing easiness and significance of the bolted joints. Due to the intricacy involved in manufacturing process of thermoset leaf springs, the production capability is limited. Hence an attempt is made to fabricate the composite leaf spring using discontinuous glass fiber reinforced polypropylene by injection molding process and the preliminary test results are reported elsewhere [29]. Prior investigations [13–26] focused the joint performance of continuous fiber thermosets and thermoplastics. However, there is no work reported on the joint behavior of discontinuous thermoplastic composites. The present work studied the static and dynamic performance of discontinuous thermoplastic leaf spring joint along with its failure morphology. Influence of bolt–hole clearance of the joint is also investigated in this work.

2. Joint strength evaluation methodology

2.1. Test material and joint configuration

In the present investigation, 20% glass fiber reinforced polypropylene (Saint Gobain) is injection molded into leaf spring. During molding, barrel temperature was kept at 255, 250 and 240 °C at first, second and third zone, detailed injection molding conditions adopted for manufacturing the leaf spring are reported elsewhere [29]. Weight average fiber length determined by fiber ash test of the chosen SFPP injection molded material is 0.44 mm and the fiber diameter is 0.01 mm [29]. Young's modulus, tensile strength and the density of chosen 20% discontinuous glass fiber reinforced polypropylene are 3500 MPa, 72 MPa and 1.03 g/cm^3 [30]. Leaf spring design has been done based on the design load and mechanical properties of 20% glass fiber reinforced polypropylene material. Detailed procedure adopted for the optimum design of variable width mono leaf spring is reported elsewhere [31]. Flat end portion is cut from the molded leaf spring and considered for the evaluation of the joint strength. Fig. 1 shows the detail geometry of injection molded leaf spring and flat end part sectioned for the joint strength evaluation. Drilling is cautiously done with the aid of appropriate fixtures to reduce delamination defects. In addition, discontinuous nature of the fibers in the base resin does not cause any delamination defect unlike continuous reinforced fiber composite during drilling. Length of the plate is taken as 30 mm due to the available portion of the leaf spring without any curvature and its width is 25 mm. Distance from the edge to the center of the hole is 5 mm. Distance between the holes is 10 mm and are symmetrically located in the 25 mm width of the plate. The above configuration of the two parallel pin joint with 4 mm hole diameter is decided after finite element analysis and detail investigation is reported elsewhere [32].

2.2. Experimental procedure

Fig. 2 shows experimental arrangement made for the joint performance evaluation. Universal servo hydraulic testing facility

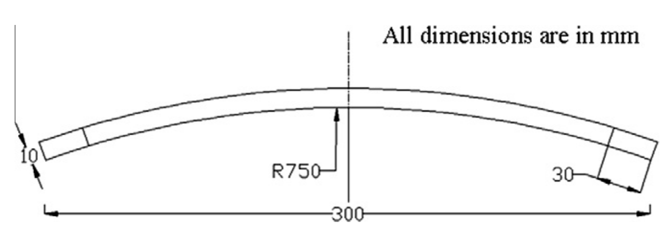

Fig. 1. Geometry of molded leaf spring indicating flat end portion for the evaluation of joint strength.