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Effect of reinforced fiber length on the joint performance of thermoplastic leaf spring

C. Subramanian, S. Senthilvelan *

Department of Mechanical Engineering, Indian Institute of Technology Guwahati, Guwahati 781 039, India

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ABSTRACT

Joint strength plays a significant role in the performance of leaf spring suspension system. Current work reported the influence of reinforced fiber length on the performance of injection molded thermoplastic leaf spring joint. Leaf springs were molded using 20% short, long glass fiber reinforced polypropylene as well as unreinforced polypropylene and evaluated for the joint strength. Servo hydraulic test facility with suitable fixture is utilized to evaluate the leaf spring joint performance under static and dynamic conditions. Test joints were subjected to completely reversed fatigue loads, wherein long fiber reinforced leaf spring joint exhibited superior performance at high cycle fatigue conditions than that of short fiber reinforced and unreinforced polypropylene leaf spring joints. However, at low cycle fatigue loading conditions, unreinforced and short glass fiber reinforced leaf spring exhibited superior performance than that of long glass fiber reinforced leaf spring joint. High notch sensitivity characteristics of the long glass fiber reinforced polypropylene material contributed to this inferior performance. Load–deflection hysteresis plot of the long glass fiber reinforced leaf spring joint under fatigue loading conditions exhibited a lesser amount of hole elongation compared to that of short glass fiber and unreinforced leaf spring joint. Failure morphology of tested joint under fatigue condition exhibited net-tension and shear-out failures besides bearing damages.

1. Introduction

Utilization of fiber reinforced composite materials in the automotive industries is being increased due to their high specific stiffness and strength. In this context, leaf spring made of glass fiber reinforced plastics provide improved fuel efficiency as well as riding comfort. Extensive investigations on the design and development aspects of thermoset leaf springs have been carried out in the past [1–5]. Beardmore [1] investigated the utilization of glass reinforced epoxy resin for composite leaf spring application. Glass fiber reinforced polyester leaf spring was used for railway wagon application and the transient response was studied using a shaker test rig by Hou et al. [2]. Morris [3] reported the reduced vehicle weight and improved riding characteristics of epoxy reinforced glass fiber leaf spring. Al-Qureshi [4] developed parabolic glass fiber epoxy leaf spring by hand lay-up vacuum bag process for light truck application and evaluated its performance. Lo et al. [5] developed constant width, variable thickness glass fiber reinforced epoxy leaf spring by compression molding and utilized for tank trailer application. The joint strength between leaf spring and eye end must have superior strength than that of the designed leaf spring [6] so that composite leaf springs can be a viable suspension system. In general joining of composites with composites/metals is accomplished through mechanical fastening by bolts due to low cost, simplicity and ease of repairing. Static and dynamic performance of the composite pinned joints was reported in the past with respect to the joint geometry, environment and testing conditions [7–15]. Tension, shear, bearing, cleavage and pull-through failure modes were most commonly observed and reported while evaluating the static and dynamic performance of the bolted joints [7]. Change in failure mode from bearing to shear-out is visualized with the decrease in end distance for glass fiber reinforced epoxy laminates [8]. Aktas et al. [9] observed maximum bearing load for the glass fiber epoxy composite plates in double pinned joints, when the ratio of end distance to the hole center is greater than four. The bearing strength of carbon fiber reinforced plastics could be improved by increasing the lateral compressive stress around the loaded hole [10]. Higher clamping pressure prevents delamination and found to improve the joint strength in glass fiber epoxy material [11]. Initial joint stiffness was found to be dependent on width to the diameter ratio and clamping torque found to have less effect in the pultruded glass fiber reinforced polyester resin [12]. A delay in load take up with increase in bolt hole clearance was observed by McCarthy et al. [13] and reduction in joint stiffness is reported with the increase in clearance. Static and fatigue strength of

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* Corresponding author. Tel.: +91 361 2582671; fax: +91 361 2582699.
E-mail address: ssvelan@iitg.ernet.in (S. Senthilvelan).

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Nomenclature

σ_b	bearing stress
ξ_b	bearing strain
δ_i	fastener translation at initial cycle
δ_N	fastener translation after N_f fatigue cycle
δ_p	fastener/pin displacement
Δ_N	hole elongation
d	hole diameter
K_t	theoretical/elastic stress concentration factor
K_s	strength reduction factor
P	maximum load obtained before failure
Q	notch sensitivity factor
t	thickness of the composite plate

the graphite–epoxy laminate is found to be improved with higher clamping torque [14]. Chen [15] investigated static and fatigue performance on graphite/epoxy laminate and observed the increase in hole elongation under hygrothermal cycling. Pinnell [16] observed higher open and filled hole tensile strength in thermoplastic than thermoset composites and reported a greater stress relief at the hole edge in thermoplastic material. Higher notch sensitivity of thermoset than thermoplastic material provides lower bearing strength to the composite for the same reinforced graphite fibers. Swanson et al. [17] observed superior open hole performance under fatigue loading for toughened matrix system and also reported the enhancement in retaining the residual strength. Carlsson et al. [18] confirmed higher notch sensitivity of graphite polyetherketone composite than graphite epoxy composite and highlighted the importance of stress relieving mechanism in reducing the notch sensitivity. Ferreira et al. [19] confirmed that stress concentration is found be more prominent in static and lower cycle fatigue for fiber reinforced polypropylene material. Very few works have reported the performance of composite leaf spring joint. Hou et al. [20] proposed 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 is reported as the main failure mode for the developed leaf spring eye end. Shokrieh and Rezai [21] proposed four different types of end joints for the glass fiber reinforced epoxy leaf springs and highlighted the manufacturing easiness and significance of the bolted joints. Prior investigation [1–5], reported design and development aspects of thermoset leaf springs, however due to intricacy involved in fabricating thermoset leaf springs; the production capability is highly limited. Hence an attempt is made with discontinuous glass fiber reinforced polypropylene by injection molding the leaf spring and its preliminary performance characteristic is reported elsewhere [22]. Prior investigations [7–20] focused the bolted joint strength performance and failure mechanisms of continuous fiber thermosets and thermoplastics. Since there is no attempt made to investigate the joint behavior of discontinuous thermoplastic composites, present investigation focused the same. In the present work, static and dynamic performance of the injection molded unreinforced, short, long glass fiber reinforced polypropylene leaf spring joints are evaluated. Influence of reinforced fiber length over joint performance and failure morphology of the leaf spring joints were investigated.

2. Joint strength evaluation methodology

2.1. Test material and joint configuration

Table 1
Mechanical properties of glass-reinforced polypropylene [23].

Material	Young's modulus (MPa)	Tensile strength (MPa)	Density (g/cm^3)	Volume fraction (%)
Long glass fiber polypropylene	4500	135	1.04	20
Short glass fiber polypropylene	3500	72	1.03	20
Unreinforced polypropylene	1700	27	0.91	0

Leaf springs are injection molded from 20% short glass fiber reinforced polypropylene (SFPP), 20% long glass fiber reinforced polypropylene (LFPP), and unreinforced polypropylene (UFPP). Mechanical properties of the selected material are listed in Table 1 [23]. Leaf spring design was carried out based on the design load and mechanical properties of 20% glass fiber reinforced polypropylene material. Detailed procedures adopted for the optimum design of variable width mono leaf spring is reported elsewhere [24]. The retention of fiber length in long glass fiber reinforced material was 1.25 mm (weight average) and short glass fiber reinforced material was 0.44 mm as reported elsewhere [22]. Flat end portion is cut from the molded leaf spring and considered for the evaluation of the joint strength. Figs. 1a and 1b shows the detail geometry of the injection molded leaf spring and flat end part removed for the joint strength evaluation. The molded leaf spring is shown in Fig. 1c. Drilling is cautiously done with the aid of appropriate fix-

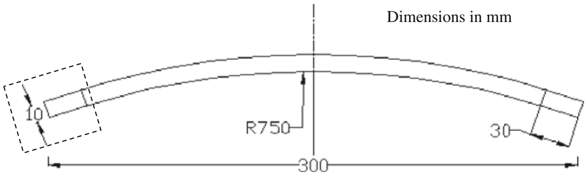

Fig. 1a. Geometry of molded leaf spring indicating flat end portion for the evaluation of joint strength.

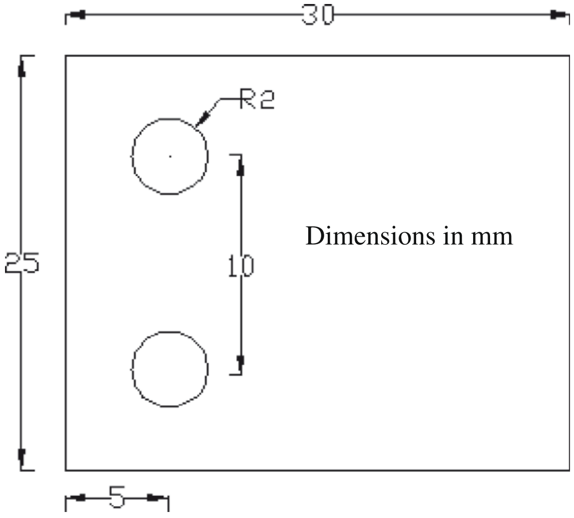

Fig. 1b. Details of holes in the sectioned flat portion of the leaf spring.