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Design of Composite Track Pin for High Mobility Tracked Vehicles

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Key Words : tracked vehicle, track pin, rubber bushing, composite pin

ABSTRACT

Since the track pin is subjected to large transverse track tension from the track link, conventional track pins for high mobility vehicles are usually made of high strength steel, which increases the weight of tracked vehicles due to the high density of steel. In this paper, several composite materials were employed for track pin design to reduce weight of track pin as well as to enhance the fatigue life of rubber bushings. Especially the effects of shear stiffness of the composites on the life of rubber bushing were investigated.

기호설명

F : track tension force

W : strain energy function

λ: extension ratio

1. INTRODUCTION

Track links for high mobility tracked vehicles usually consist of track shoe bodies, track pins, rubber pads, end-connectors, and rubber bushings. The track link transfers the driving torque from the engine to the vehicle by the friction force between the ground and the track rubber pad. In addition to torque transmission, the track absorbs impact load from the ground. The required strength of the track link is order of 10^5 N in the longitudinal direction, in addition to various smaller loads from the ground and roadwheels.

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Since the track pin is subjected to large transverse track tension from the track link, conventional track pins for high mobility vehicles are usually made of high strength steel, such as forged chrome-molybdenum steel rods, which increases the weight of tracked vehicles due to the high density of steel. The increase of track weight also increases the rolling resistance of tracked vehicles, which decreases the fuel efficiency and mobility of the tracked vehicle. Therefore, the weight reduction of track pins is an important design factor for tracked vehicles. Another design requirement for the track pin is high flexural rigidity to distribute track tension load uniformly on the rubber bushing. Pins with low flexible rigidity cause uneven load distribution and excessive bushing wear at the ends of pin due to the pin bending [1], which results in the decrease of bushing life.

These three requirements of high strength, high stiffness, and low weight of track pins are not easy to satisfy simultaneously with conventional metal, but can be satisfied by fiber reinforced composite material. Carbon fiber reinforced composite materials might be employed to solve the problem of cylindrical pins owing to its high specific stiffness and high strength [2]. However, there have been few attempts on the composite track pins, also the relation between the rubber bushing life and the composite track pin stiffness was little investigated. Therefore, in this paper, several composite materials were employed for track pin design to reduce weight of track pin as well as to enhance the fatigue life of rubber bushings. Especially the effects of shear stiffness of the composites on the life of rubber bushing were investigated.

2. BASIC REQUIREMENTS

In the double pin type track link as shown in Fig. 1, the shoe bodies are connected with each other by the track pin and the end-connectors.

When the track tension force, F, is applied on the track link, the concentration of shear forces occurs at both ends of the track pin near the end-connectors. Also the shear force in the rubber bushing is produced as the rubber bushing is pressed on the pin. The maximum stress in the pin, due to the track tension, was 1080 MPa, which occurred at the center of pin. The high strength steel pin of 1200 MPa has been used for the track pin. Therefore, unidirectional glass fiber/epoxy composites (UGN 150, SK Industries) and carbon fiber/epoxy composites (USN 150, SK Industries) may be considered as substitutes for the steel, because the tensile strengths of the glass and carbon fiber/epoxy composites are 1000 MPa and 2300 MPa, respectively.

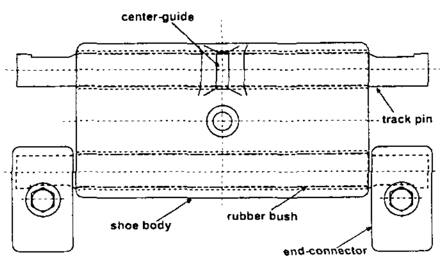


Fig. 1 Schematic diagram of a track assembly

During the operation of tracked vehicles, relative rotation between the adjacent track shoe body and the pin of ±8 degrees occurs. Fig. 2 shows the free body diagram of the track pin during rotation.

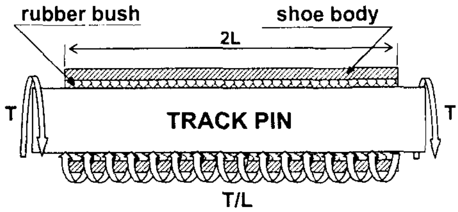


Fig. 2 Torque on the track pin and rubber bushings

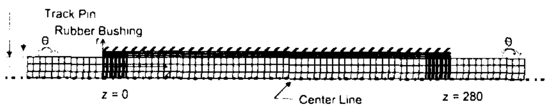
3. FINITE ELEMENT ANALYSIS

In order to investigate the relation between the rubber bushing strains and the pin stiffness, the stresses and strains of the rubber bushing under torque were calculated using finite element analysis using ABAQUS 6.3 (Hibbitt, Karlsson & Sorensen, Inc., USA) - a commercial software. Besides the finite element analysis, the closed form solution for the shear strain distribution of single lap joint was adopted [3]. The track pin and shoe body were considered as the inner and outer adherends, respectively. The rubber bushing was considered as an adhesive with linear elastic material properties. Even though the strain of the bushing could be calculated easily using the closed form solution, the strains from the linear analytic model were found to be much smaller than those of the finite element analysis results because the linear joint model could not depict well the nonlinear elastic behavior of the rubber bushing when the shear strain was above 50%. Therefore, the finite element analysis was employed to calculate the strain of the bushing with the nonlinear elastic rubber properties.

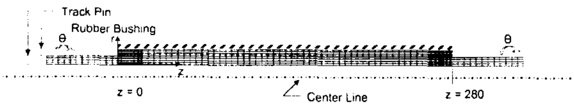
Fig. 3 shows the finite element mesh for the rubber bushing and the track pin in which quadratic quadrilateral axisymmetric elements with torsion (CGAX8R) were used for the track pin and the rubber bushing. Fig. 3(a) shows the finite element model of the solid pin. Fig. 3(b) shows the finite element model of hollow type track pin in which the total numbers of nodes and elements were 800 and 2641, respectively. The size of the elements was decreased towards both ends of rubber bushing range for the accurate calculation of the shear strain. All the nodes on the outer surface of the rubber bushing were fixed because there is no sliding between the bushing and the shoe body. The Mooney Rivlin model with constants C_{10} = 1.18 MPa and C_{01}=0.45 MPa were used to model the hyper-elastic properties of the rubber bushing as follows:

$$W = C_{10}\left(\lambda_1^2 + \lambda_2^2 + \lambda_3^2 - 3\right) + C_{01}\left(\lambda_1^2\lambda_2^2 + \lambda_2^2\lambda_3^2 + \lambda_3^2\lambda_1^2 - 3\right) \quad (1)$$

where, W is strain energy function, λ is extension ratio.



(a)



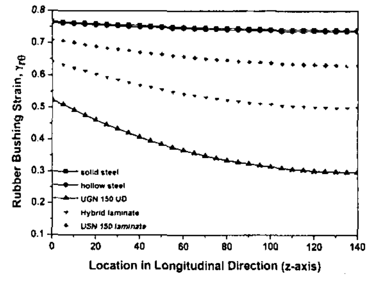
(b)

Fig. 3 Finite element model of the bushing and pin, (a) solid pin, (b) hollow pin

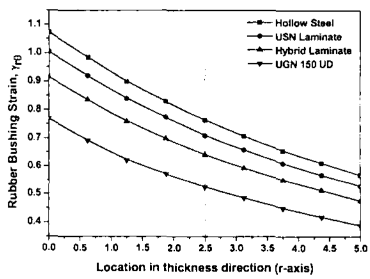
4. RESULTS

In order to investigate the effect of torsional rigidity of the pin on the strain of the rubber bushing, four kinds of material were employed for the track pin such as steel, unidirectional glass fiber/epoxy composites, hybrid composites composed of glass and carbon fiber/epoxy, and carbon fiber/epoxy laminates. The cross sections of the three pins were same. The shear moduli of the materials were 80 GPa, 4.4 GPa, 11 GPa, and 24 GPa, respectively. The rubber bushing has the maximum shear strain at the both ends (z=0, z=280 mm), and the minimum strain at the center of the track pin (z=140 mm) as shown in Fig. 4(a). The shear strain of the bushing decreased as the distance from the pin surface increased as shown in Fig. 4(b). The strains of Fig. 4(a) represent the strains at the average thickness, which is indicated with the center line in Fig. 4(b), where r = 2.5 mm.

The shear strain of the rubber bushing decreased as the shear modulus of the pin material decreased. The strains of the steel solid pin and hollow pin were almost same with each other. The shear strain of the rubber bushing on the glass fiber/epoxy composite pin was 31% ~ 60% less than that on the steel pin, which was caused by the low torsional rigidity of the composite pin (5.5% of the steel pin). The low shear strain of the bushing might increase the endurance life of the bushing, because the fatigue life of rubber part, N_f, is given by $N_f = \alpha W^{\beta}$ (α and β: material constants, and W: strain density) [4]. Therefore, the composite track pins were designed using unidirectional glass and carbon fiber/epoxy composites which have low shear moduli but higher longitudinal moduli. Fig. 5 shows the track pin designed which has only 50 % weight of the conventional steel pin.



(a)



(b)

Fig. 4 Rubber bushing strain w.r.t the composite track pin stiffness, (a) strain variation in longitudinal axis, (b) strain variation in the radial direction.

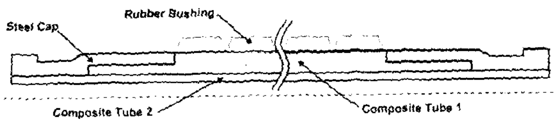


Fig. 5 Configuration of the composite track pin (An international and a domestic patent are pending for the design.)

5. DISCUSSIONS

In this research, composite track pins for high mobility tracked vehicles were developed. The weight reduction for the composite pin was 50% compared to the conventional steel pin and it was expected that the endurance life of the rubber bushing would increase because the shear strain of the rubber bushing on the composite pin was 31% less than that of the steel pin.

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