Composite Structures 134 (2015) 378–383

Contents lists available at ScienceDirect

Composite Structures

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

Investigation of creep phenomenon on composite material for bolt connections

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ARTICLE INFO

Article history:
Available online 29 August 2015

Keywords:
Creep
Carbon fibre reinforced plastic
Bolt connection

ABSTRACT

One of the main targets in automotive design is weight reduction. This reduction leads to the reduction of gas emissions. Designers tend to use innovative materials in the automotive field such as plastics and composites. To use the right material for the right application, multi material solutions are increasingly adopted. To join dissimilar materials, solutions like adhesive, bolt and nuts, and riveting are necessary. It is necessary to know the behaviour of the materials to be joined, under different loading conditions to ensure the joint. In this work, a bolt connection between composite and aluminium plates has been considered. The behaviour of a carbon fibre reinforced material under compression load, taking into account creep is studied. A specific experimental equipment has been designed and built. A series of experimental compressive tests, in the laminate thickness direction, have been done on carbon fibre reinforced material specimens. Different set-ups in terms of temperature, compression load and surface roughness have been investigated. The obtained results are presented and discussed. A mathematical model will be proposed for interpolation of the obtained results. Finally, a possible strategy for reducing the tightness loss in the initial phase of the joint life is proposed.

1. Introduction

Nowadays one of the main targets in the automotive design is weight reduction. This is a very important aspect because it is one of the key factors for the reduction of both fuel consumption and pollutant emissions. Indeed, gas emissions, in particular the production of the carbon dioxide, are directly proportional to the fuel consumptions that are directly influenced by the weight of the car. Consequently, the reduction of the weight leads to the reduction of GHG emissions that are responsible for the present impressive climate change. On the other side, along the years, the weight of the car has had a continuous growth. This is due to the tendency to equip vehicles with more devices and gadgets. In this overview, it is clear that in the design of the new vehicles attention is focused on the containment of the structures weight. To this aim, designers put their attention on the use of lightweight materials such as reinforced plastics and composites. The target is to use the right material for the right application. For this reason, even more often, multi material solutions are adopted in the design. In these cases, it is also necessary to use different joining technologies. Indeed, the traditional joining technologies adopted in the car manufacturing, such as the spot welding, cannot be used when different types of materials have to be joined together. Consequently, solutions like adhesive, bolt and nuts or riveting are taken into consideration. To ensure a correct working of the connection, it is also necessary to investigate in detail and to know the behaviour of the materials to be joined under different loading conditions.

In this frame, the research activity, whose results are reported in this work, has been focused on the study of a bolt connection between a part made in aluminium and a part made in composite material. It is well known that, in this type of connection, the bolt is tightened to give enough compression force between the joined members. However, creep phenomenon, in particular on the composite part, could cause a loosening of a tight bolt with consequently malfunction of the joining also with possible problems from a safety point of view, depending on the considered application. For these reasons, in this work, the creep effect due to compression load on a carbon fibre material in epoxy resin has been investigated. In particular, the behaviour in a direction perpendicular to the fibre has been studied. A specific experimental testing machine has been developed to this aim. With this machine, a series of experimental creep compression tests have been carried out.

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http://dx.doi.org/10.1016/j.compstruct.2015.08.061
0263-8223/

The effect of the temperature, the amount of the load and the surface roughness has been investigated.

1.1. State of the art

Usually the matrix material of a composite has a viscoelastic behaviour. For this reason, the composite materials are subjected to creep phenomenon [1]. The creep effects on material are studied for many years, and different behaviour models have been proposed, as discussed for example by Findley et al. [2].

In particular, the creep behaviour of the composite is influenced by different aspects such as the temperature, the stress level, and the moisture [1]. Different works, where the creep behaviour in the direction of the fibre is considered, have been published in the past. In this case the behaviour of the material is driven both by the fibres and by the matrix. Test on creep in composite in the fibre direction has been carried out by Kim and McMeeking [3]. Maksimov and Plume have investigated the long term creep behaviour of aramid fibres [4]. Bending and tensile creep testing on carbon fibre/epoxy matrix composite has been studied by Goertzen and Kessler [5]. Accelerated tests have been done by Raghavan and Meshii [1], by Abdel-Magid et al. [6] and by Scott et al. [7]. The effect of different types of fibre materials has been investigated by Maksimov and Plume [8]. Longitudinal compressive load and long term tests have been performed by Scott and Zureich [9] on beams made in pultruded E-glass/vinylester composite for civil-engineering construction. Always concerning the civil applications, similar studies have been carried out by Holmes and Rahman [10], by Mosallam and Bank [11,12] and by Wang et al. [13]. Kouadri-Boudjelthia et al. [14] have studied the effect of the temperature, the load and the crystallinity rate of a composite material made of unsaturated polyester matrix and reinforced with randomly oriented type C glass fibres. The creep behaviour of the material has been modelled using power law formulation. Other prediction models for the creep behaviour have been proposed by Guedes et al. [15] and by Raghavan and Meshii [1].

The creep behaviour of composite materials in the direction perpendicular to the fibre is mainly governed by the matrix material as demonstrated by Guedes et al. [16]. This behaviour can contribute to the relaxation phenomenon in bolted connections. Also in this case some studies have been carried out in the past for example by Weerth and Ortloff [17], Pang and Wang [18] and by Chen and Kung [19]. Specific works on the bolt connection of parts made with composite materials have been published by Shivakumar and Crews [20]. They studied a connection of two plates made of T300/5208 graphite/epoxy, predicting the relaxation after a long period of time. The temperature and the moisture effects have been also considered in the study. Shivakumar and Crews [20] have also proposed a predictive model. A study of E-glass/vinylester bolted joints has been carried out by Fox [21]. In this study relaxation and shear tests were carried out. Bolted connections with composite, in particular E-glass/vinyl-ester have been studied by Weerth and Ortloff [17]. The loss in the tight load has been measured and the data have been fitted with a power law equation, which allows prediction of the relaxation. Similar power law formulation has been used to predict the loss of load in the bolt by Pelletier et al. [22].

2. Materials and methods

2.1. Material

In this work the compression creep behaviour of a carbon fibre/epoxy resin has been investigated. In particular, a twill carbon 2×2 800 UTS 24K with epoxy resin with a cure of 90 min at 120 °C has been chosen. The stacking sequence has been one layer of 380 gsm and seven layers of 800 gsm. The 380 gsm layer is on the side of the mould. The cured ply of 800 gsm is 0.88 mm thick while the one of 380 gsm is 0.45 mm thick. The total thickness of the laminate is 6.6 mm. It has been decided to use specimens with a cylindrical shape, with a diameter of 20 mm, as shown in Fig. 1. The properties of the material are reported in Table 1.

2.2. Testing machine

To perform the creep compressions tests a dedicated testing machine has been developed. The testing machine is shown in Figs. 2 and 3. It is based on a lever principle. It is characterized by a frame where the lever is hinged. The compression stress is created applying a load on one side of the lever, then the lever pushes on a column, which applies the compressive stress on the specimens. The machine has been designed to test three different specimens at the same time. These specimens have been positioned between rigid metal plates. These plates are positioned between two steel columns, one above and one below the test area, the upper column applies the load to the plates. To ensure only load perpendicular to the specimens, the plates are driven by two additional smaller lateral columns. The lever in the upper part is in contact with the main column only in a single point, by means of a steel ball positioned on the upper part of the column. The applied load is measured with a load cell positioned in the lower part of the column. To measure the compression displacement,

Fig. 1. Specimens for the creep compression tests.

Table 1
Properties of the material examined.

Properties	Unit	Standard	Value
Tensile 0° modulus	GPa	ISO 527-4	61.8
Tensile 90° modulus	GPa	ISO 527-4	61.1
Compr. 0° modulus	GPa	prEN 2850 B2	57.2
Compr. 90° modulus	GPa	prEN 2850 B2	55.5
Poisson's ratio 0°	–	ISO 527-4	0.07
Poisson's ratio 90°	–	ISO 527-4	0.04
In plane shear modulus	GPa	EN 6031	3.83
Tensile 0° strength	MPa	ISO 527-4	1034.1
Tensile 90° strength	MPa	ISO 527-4	930.1
Compr. 0° strength	MPa	prEN 2850 B2	541.7
Compr. 90° strength	MPa	prEN 2850 B2	510.8
In plane shear strength	MPa	EN 6031	86.1
Density	kg/dm^3	–	1.5
Tensile strain 0°	%	ISO 527-4	1.66
Tensile strain 90°	%	ISO 527-4	1.5
ILSS 0°	MPa	ISO 14130/1	52
ILSS 90°	MPa	ISO 14130/1	51.7