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Original Research Article

Expectancy of the lifetime of bonded steel joints due to long-term shear loading

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ABSTRACT

In this paper, the time-dependent behaviour, shear creep behaviour, of double lap galvanized steel joints loaded in shear by tension, is investigated at room temperature. The studied joints are assembled by bonding the galvanized steel adherends by a rigid structural adhesive (epoxy). Two thicknesses of the bondline (0.35 mm and 0.65 mm) are used. The specimens are tested under different shear stress levels. Well-known rheological and empirical models are used to describe the behaviour of the adhesive. The relevant models parameters are experimentally estimated. The time-to-failure of the studied specimens is predicted in accordance with short-term tests (rapid-loading tests) performed on similar specimens. The applied shear stresses for particular lifetimes of the bonded joints are estimated.

1. Introduction

In spite of the encouraging properties, by which the structural adhesives are characterized, the use of these materials in the structural engineering fields needs to be validated. This needs intensive test plans to assess both the short-term and long-term behaviours under defined conditions of mechanical and environmental loading. By demonstrating that bonded joints can carry predefined loads over the lifetime of the joint, the engineering industry would become convinced to use such a technique in its applications.

Long-term assessment is more difficult than the short-term or the accelerated testing because special techniques and equipments are needed for long time; therefore, the costs especially when testing a large number of specimens to accommodate all conditions might increase. However, the long-term testing results, under real conditions, are still more realistic.

The phenomenon of the increase in strain or deformation of a material with time is called creep. This phenomenon occurs when the material is subjected to a constant load over an extended period of time (i.e. time-dependent deformation). The time-dependent deformation increases as the applied load, temperature, and relative humidity increase.

Adhesives, as being polymers, are viscoelastic materials that can deform over a period of time at relatively low stress levels and low temperatures. The durability of these materials, therefore, is expected to be reduced due to the loss of their strength that resulted from the creep phenomenon. This paper presents a contribution to estimate the lifetime of adhesively bonded overlap steel joints loaded for long time and which can be used in lightweight steel constructions.

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2. State-of-the-art

The investigations on the time-dependent behaviour of structural adhesives are still modest. Many researchers have focused on the creep behaviour of one of the available structural adhesives, which is the epoxy, and their investigations were set to study the creep behaviour of it in tension loading. The tension creep of the adhesive was basically described using a particular creep model, Burger's model, whose parameters were found for such loading case [1,2].

The shear creep of an epoxy, used to connect fibre reinforced polymer (FRP) to the concrete, was studied and assessed in [3,4]. Both of them described the long-term behaviour by using rheological models and empirical equations and found the relevant parameters of the used models. It was also recognized by the finite element analysis performed in [3], that the creep of epoxy might result in stress redistribution at the concrete–FRP interfaces.

In stainless steel lap joints bonded by an epoxy adhesive, the time over which the adhesive resisted sustained loads was recorded and evaluated by [5]. Specimens loaded by 20% and 40% of the main static failure load sustained the loads over six months without failure and were showing no apparent damage which might indicate to the existence of the so-called endurance limit.

The behaviour of the bonded metallic single lap joints with epoxy and polyurethane adhesives was evaluated as a function of the load applied by [6]. It was found that joints loaded above 60% of the static strength account for a relatively small lifespan. Epoxy exhibited a higher creep resistance than polyurethane. The safe region for the use of the joints was determined basing on the curve stabilization observed in the load–lifespan curves.

The creep behaviour investigated by the above mentioned researches was obtained by functioning the joint under sustained loads. This kind of long-term tests will also be illustrated here.

3. The principle of creep tests on the bonded joints

The creep of the bonded joint under sustained loads can be done similar to the procedure of (ETAG001-Part five, [7]). The principle of this test method is to maintain the applied load on the joint at a specific level (i.e. at predefined applied stress, usually taken as a ratio of the strength capacity of the same joint under short-term or rapid test). The deformation of the joint, mainly the adhesive, has to be measured until it appears to have stabilized or for at least three months. The frequency of monitoring the deformations (the displacements) has to be high initially in the early stages as the displacements are greatest in these stages and can be reduced with time.

The displacements measured in the tests have to be extrapolated to a specific lifetime according to a known model. The extrapolated displacements shall be less than the average value of the displacements obtained by reference tests (short-term or rapid tests).

4. Modelling of the creep behaviour of the adhesive

The creep behaviour of viscoelastic materials has been modelled by empirical models such as power-law equations like Bailey-Norton and Findley's model and also by mechanical models such as Kelvin–Voigt and Burger's models. However, Bailey-Norton and Kelvin–Voigt models do not consider the instantaneous deformation; therefore, in this work only Findley's and Burger's models are used.

Findley's approach has been developed since 1956 [8] and many equations were derived from it till this time. The Simplified Findley's model is given for the shear case as:

$$\gamma(t) = \gamma_0 + At^B \tag{1}$$

where $\gamma(t)$ is the shear strain over the time t, γ_0 is the instantaneous shear strain when $t = 0$ (measured directly after applying the load), and A and B are constants (tuning factors in the shear case evaluated by a regression analysis of the deformations measured during the creep test).

Due to the difficulties in measuring the exact instantaneous strain γ_0, it can be determined separately by the short-term or rapid-loading test on a specimen of material identical to that used in the creep test being evaluated [8]. The instantaneous strain γ_0 by this way is defined by Eq. (2):

$$\gamma_0 = \frac{\tau}{G_{t(0)}} \tag{2}$$

where τ is the applied shear stress and $G_{t(0)}$ is the initial shear elasticity modulus taken from rapid-loading test.

The most common mechanical model in literature being used to describe the creep behaviour of the adhesives (as being polymers) is Burger's model which consists of two simple models, Maxwell and Kelvin–Voigt models, attached together in series.

The Burger's model in shear (Fig. 1) is given in Eq. (3):

$$\gamma(t) = \frac{\tau}{G_M} + \frac{\tau}{\lambda_M} \cdot t + \frac{\tau}{G_K}\left(1 - e^{-(G_K/\lambda_K)t}\right) \tag{3}$$

In which, τ is the constant applied shear stress; G_M, G_K, λ_M and λ_K represent the shear elasticity and the shear viscosity of Maxwell and Kelvin elements respectively. It is obvious that the first term in Eq. (3) represents γ_0, the instantaneous shear strain when $t = 0$.

5. Creep tests of adhesively bonded steel joints

5.1. Studied joint

Double lap shear joints, whose geometry is shown in Fig. 2, were selected. The common hot-dip galvanized steel D × 51D

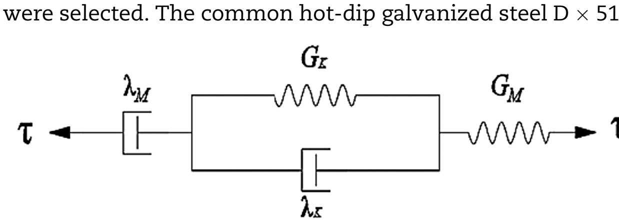

Fig. 1 – Mechanical Burger's model.