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Modelling of the creep behaviour of adhesive joints using Arcan tests

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1. Introduction

Structural adhesive bonding is being increasingly used in civil engineering applications. This joining technique has in fact several advantages: weight reduction, facility to joint different materials, uniform stress distribution, no heat production. This last feature is particularly interesting for offshore activities, where there may be some need to connect new elements to existing structures without constraining their service properties [1]–[3]. However, there are still some issues preventing a wider development of this technique such as the durability of structural adhesive bonding. The firm Cold Pad developed adhesively bonded fastener solutions (FIGURE 1 – (a)) whose aim is to replace welding by structural bonding, for repair or reinforcement of steel structures in offshore area. A specific installation tool (FIGURE 1 – (b)) was also developed to ensure precise control of the bonding operation between the two substrates [4].

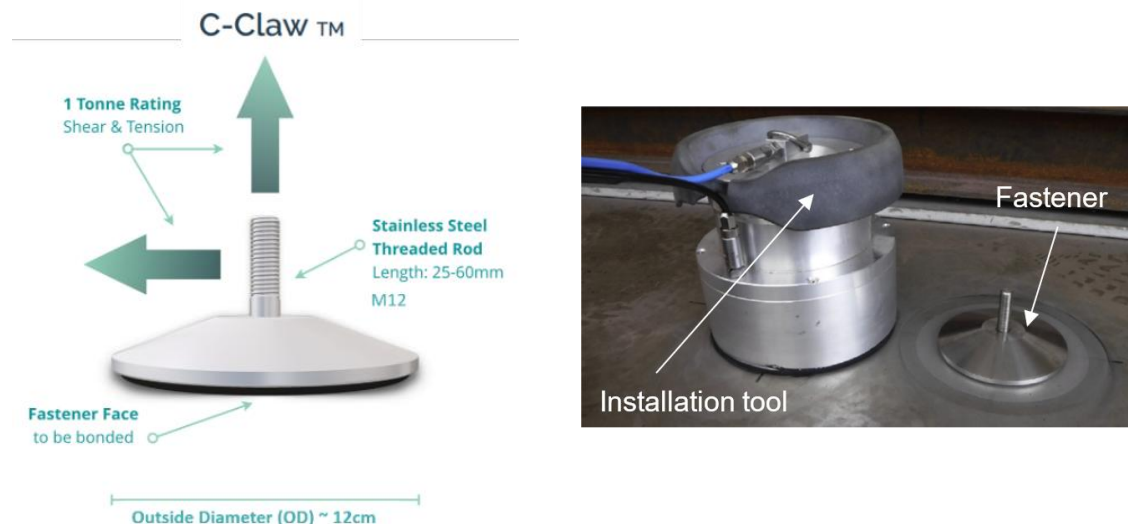


FIGURE 1 – (a) Bonded fastener solution (b) Installation tool developed by Cold Pad [4]

Regarding the durability issue raised by such a solution, as specific protections against humidity diffusion have been provided, creep appears to be one of the main phenomena that must be studied for the considered case. To do so, experimental investigations were carried out at real scale on the assembly in creep for two geometries of a bonded fastener, at different stress levels and under different load situations (tension and shear) using a methacrylate adhesive [5]. However, these investigations remain specific to the studied fastener geometry preventing their use for creep prediction of alternative geometries. Most of existing literature focused on the creep characterisation on bulk samples of the adhesive. Yet, as interphase may influence this behaviour, studies at the scale of the adhesive joint are required.

Arcan test (FIGURE 2 – (a)) presents several advantages compared to other tests at the scale of the adhesive joint: beaks closed to the bonded surfaces to reduce the edge effects (FIGURE 2 – (b)); different type of loads can be applied to the adhesive layer. It was therefore chosen for this study. The selected experimental set-up is the Arcan test TCS developed by Créac'hcadec et al. [6]. The present study will focus on the analysis of the creep behaviour of bonded assemblies using the Adekit A310-1 methacrylate adhesive.

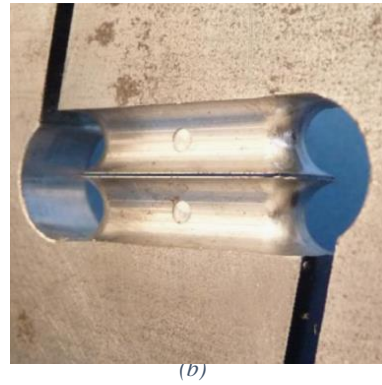


FIGURE 2 - (a) Arcan test TCS developed by Créac'hcadec et al. [6], (b) Zoom on the Arcan TCS beaks [6]

2. Materials and methods

The thickness of the adhesive joints is defined by the geometry of the samples. In this work, the tested adhesive thickness is 200 μm . The bonded surface is $9.54 \times 25.4 \text{ mm}^2$. To investigate the creep behaviour using the Arcan test, an adapted creep testing machine was developed (FIGURE 3). The load applied to the specimen is created thanks to gravity. It is amplified with two level arms. To control the loading speed, the upper arm is supported by a threaded rod. The rod is removed progressively to apply the load on the sample.

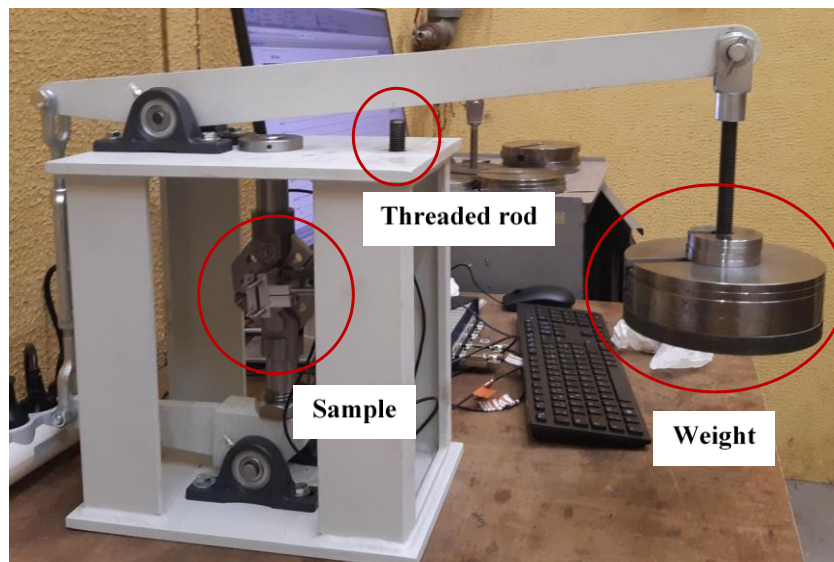


FIGURE 3 - Creep mechanical frame

A Digital Image Correlation (DIC) technique is often used to extract displacements data with Arcan tests [7]. However, for this study, Linear Variable Differential Transformer (LVDT) sensors were chosen to measure the displacements of the bonded assembly. The relevant displacements were in the normal and orthogonal directions of the bonded surfaces. A specific system was designed to fix the sensors on the beaks of the sample (FIGURE 4 **Erreur ! Source du renvoi introuvable.**). For tensile tests, the relevant displacement is the one that is normal to the bonded surface. To validate the displacement measurements with the LVDT sensors, some quasi-static investigations up to failure were done with DIC to compare the results of displacement data with this method to the measure with LVDT sensors. These tests enabled to validate the measurement method with the LVDT sensors.

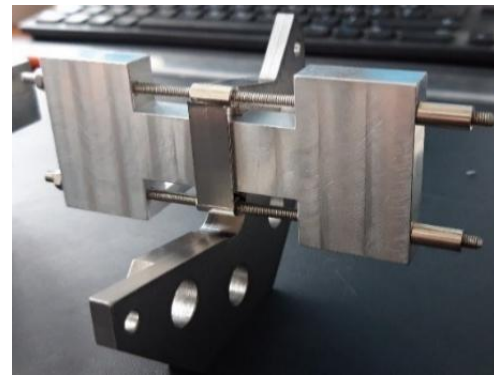
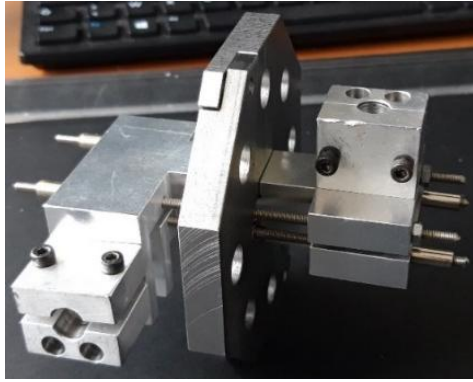


FIGURE 4 - Support for the LVDT sensors adapted to the sample

3. Creep test investigations

Preliminary quasi-static investigations up to failure were carried out to determine the monotonic ultimate capacities of the adhesive joints. The test was repeated at least five times. The temperature of the test was 20°C. The average ultimate capacity in tension, noted T_{ult} , is 17.9 MPa with a standard deviation of 10%.

The creep tests in tension were performed between 50% and 70% of T_{ult} at 20°C. FIGURE 5 and FIGURE 6 detail the results of these tests. FIGURE 5 highlights that the logarithm of the time to failure (t_f) is linearly linked to the normal stress applied to the adhesive joint. This observation was already made in other studies [8]. FIGURE 6 shows the displacements normal to the bonded surface during the creep tests as function of the normalised time. This time is defined as the ratio of the time and t_f . It can be noticed that all the tests present the three creep stages. This definition of normalised time has already been used for previous creep studies [9], [10].

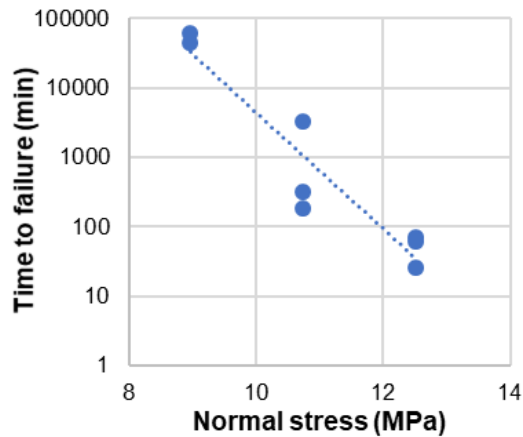


FIGURE 5 - Time to failure as function of the normal stress for creep tests in tension

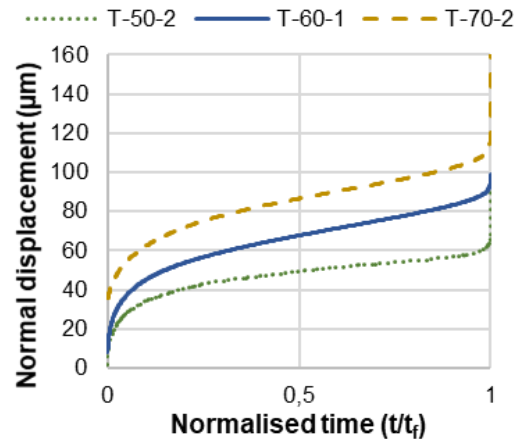


FIGURE 6 - Normal displacement depending on time during tensile creep tests at 50%, 60% and 70% of T_{ult}

To investigate the influence of temperature on the creep behaviour of the adhesive joint, one of the frames was placed in a thermal chamber. The creep tests at high temperature were performed at 35°C and 50°C, at 50% of T_{ult} for the tensile tests. As expected, the time to failure declines sharply when the temperature increases (FIGURE 7). The logarithm of the time to failure seems linearly linked to the temperature. FIGURE 8 shows the creep displacement at the studied temperature.

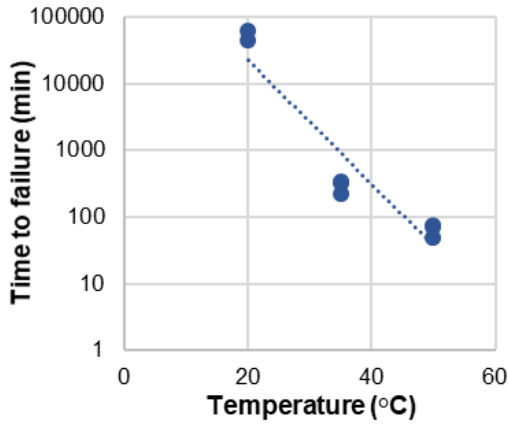


FIGURE 7 - Time to failure as function of the temperature for creep tests in tension at 50% of T_{ult}

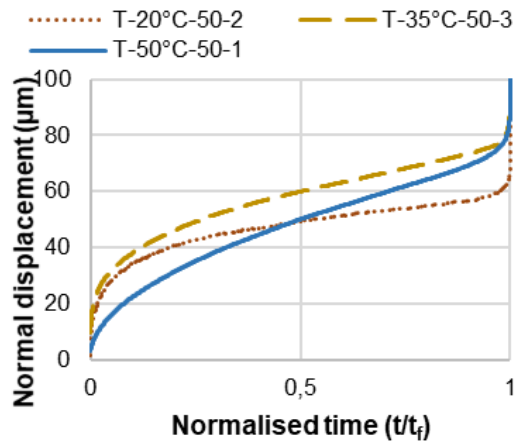


FIGURE 8 - Normal displacement depending on time during creep tests at 50% of T_{ult} at 20°C, 35°C and 50°C

4. Modelling approach

To describe the observed creep behaviour, the Burger model is used [11]. This model gives the creep strain ϵ_{creep} as a function of the time t , the creep stress σ_0 and three parameters η_1 , E_2 and η_2 with the following equation:

$$\epsilon_{creep}(t) = \sigma_0 \times \left(\frac{t}{\eta_1} + \frac{1}{E_2} \times \left(1 - \exp\left(-\frac{E_2}{\eta_2} t\right) \right) \right)$$

The creep parameters were identified for all the presented Arcan tests. It enables to develop a nonlinear Burger model for which the parameters depend on the creep stress.

To verify the accuracy of this modelling approach, the nonlinear Burger law was implemented in a numerical model of the fastener C-Claw in the case of tension load. The used model is the same than the one in the study of Djeumen et al. [5] and Loiseau et al. [9]. The results of these simulations were then compared to the experimental data from the investigations at the scale of the fastener presented in the study of Loiseau et al. [10].

FIGURE 9 compares the results of the numerical simulation with the experimental data for the creep investigations at 60% of the ultimate capacity in tension of the fastener. We can notice a good correlation between the numerical model and the experimental data.

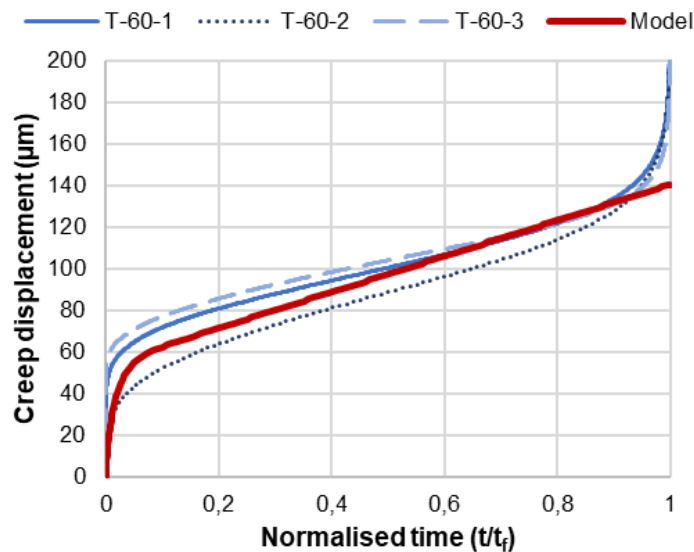


FIGURE 9 - Comparison of the numerical simulation with the experimental data of the creep tensile tests at 60% of the ultimate capacity in tension of the fastener

5. Conclusion

In this study, experimental investigations of the creep behaviour have been carried out at the scale of adhesive joints using Arcan test. To do so, dedicated resources were developed: a creep mechanical frame and a specific measurement system for the local displacements.

The Burger model was used to describe the observed creep behaviour. In tension, three load levels and three temperatures were investigated. This enabled to develop a nonlinear creep law. Consequently, the dependency of the creep parameters with the stress is considered.

The nonlinear model was implemented in a numerical model (finite element) of the fastener. The results were compared to experimental data of creep tests performed at the scale of the fastener in previous studies. A good correlation is observed between the numerical and the experimental data.

This offers interesting perspectives to develop a creep model from experimental investigations at the scale of the adhesive joint to predict the creep behaviour of bonded assemblies at the scale of the structure.

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