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Long-Term Structural Behaviour of Composite Sandwich Panels

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Abstract - New materials are great additions to the structural world dominated by concrete and steel creating sustainable products and low impact materials that can go head to head with concrete and steel. The new materials being discovered can often outperform traditional materials and have added benefits that improve the in-life performance such as thermal capabilities and sound insulation. One of these construction materials are sandwich panels made of two materials that are relatively weak in their separated state, but are improved when they are constructed together in a sandwich panel. Sandwich panels can be used for almost any section of a building. Polystyrene/cement mixed core and thin cement sheet facings sandwich panels are Australian products made of cement-polystyrene beaded mixture encapsulated between two thick cement board sheets. Long-term structural behaviour of these sandwich panels are relatively unknown. Therefore, in this study, in order to understand the creep and creep recovery behaviour and properties of those sandwich panels, a series of experimental tests have been performed and the outcomes have been explained and discussed. Based on the results of this study, values for immediate recovery, creep recovery and irrecoverable creep strain are determined and proposed. In addition, typical creep and creep recovery design charts have been developed and presented for practical applications in structural engineering.

***Keywords*:** Long-term Behaviour, Creep, Creep Recovery, Sandwich Panels, Polystyrene/cement Mixed Core, Thin Cement Sheet Facings, Design Charts

1. Introduction

The building and construction industry is ever increasing in size and the demand for houses and industrial buildings all around the world is currently greater than ever. The growing amount of houses and industrial buildings being constructed is affecting the amount of building materials being produced and is influencing the competitive prices needed to complete these. The demand for building materials has prompted the development of construction products and methods. These construction products have been carefully thought out with careful considerations for the future. The demand for building materials has prompted the development of construction products and methods. These construction products have been carefully thought out with careful considerations for the future. The environment, the purpose and efficiency of materials are all considerations that are continually thought of in the development of these materials. The considerations for the future and the effects on the environment are the main reasons why people produce construction materials. One of these construction materials are sandwich panels. Sandwich panels are made of two materials that are relatively weak in their separated state, but are improved when they are constructed together in a sandwich panel [1]. Sandwich panels can be used for almost any section of a building including roofs, walls and floors. These building sections are regularly required to provide insulation properties, weatherproofing properties and durability in addition to providing structural load bearing characteristics [2]. It is usually very common to find precast concrete panels as a part of a building's composition. Precast concrete panels are normally very strong, but are generally extremely heavy and difficult to work with. Sandwich construction form has distinct advantages over conventional structural sections because it promises high stiffness and high strength-to-weight ratio as compared with a solid member [3]. Sandwich composite structures possess excellent flexural and shear properties. Their inherent lightweight characteristics make them ideal structural components where weight reduction is desirable [4]. Thus structural sandwich panels are becoming important elements in modern lightweight construction. Among the other advantages, their good thermal insulation due to the cellular thick core makes them ideal external construction components [5]. Some recent investigations suggest their excellent energy-absorbing characteristics under high-velocity impact loading conditions [6]. Sandwich structures have been considered as potential candidate to mitigate impulsive (short duration) loads [7].

2. Background

Composite sandwich panels have gradually become more popular due to their typical benefits including strength, weight, ease of handling, durability, versatility, thermal and acoustic properties [8]. Many researchers are aware of these benefits and have undertaken detailed research and publicised large amounts of scientific papers on composite panels. Polystyrene is environmentally friendly with significantly low impact on the environment [9]. Polystyrene can be shaped into many differing shapes and has the ability to withstand deformations over a long period of time which is the reason why they are an ideal use. There are many different types of composite sandwich panels that can be constructed, but one of the strongest types of sandwich panels is a panel made of a polystyrene/cement core that is sandwiched between thin cement sheet facings [10]. The structural properties of sandwich panels constructed of polystyrene/cement cores and thin cement sheet facings have been determined and proposed for practical applications by Tabatabaiefar et al. (2015) [11]. In Australia the application of Polystyrene is for its thermal capabilities which suit the Australia climate very well. For a structural member, creep occurs when plastic deformation continues to increase under a constant stress [12]. A member may not fail under a specified load but it may deform over a long period of time causing some reduced performance (in the form of deflection) and even failure. In the case of a composite sandwich panel with a polystyrene cement core, it is difficult to predict how the panel will behave. The core is made from both a polymer and cement core. Plastic cores materials are viscoelastic and creep indefinitely under stress [10]. However, polymer foams creep at room temperature and exhibit different creep response under different temperatures [13]. When concrete is under a sustained load, there is an immediate elastic response due to the load. Then the inelastic deformation takes place, known as creep, which takes longer times to appear. The creep in concrete can be attributed to small cracks forming in the concrete, closure of air voids and water flowing out of the concrete. With the building requirements and the disadvantages of precast concrete panels, sandwich panels provide an alternative to the precast concrete panels.

3. Long-Term Behaviour

With the variety of loads that could possibly be applied to a structure, often the in service life behaviour is significant. Reviewing whether it will function correctly and without excessive deformations is a factor that can sometimes impact the performance. A sustained load will be less than the failure load but can also cause failure. Under this, load deformation can be present in the structure and when the load is removed, there may be some remaining deformation. Under a constant sustained load, the deformation can continue to progress. In some cases, this can continue through the service life or it can cause failure. It is common for the deformation to occur at varying conditions including increased temperature and humidity. This deformation under a constant stress is known as ‘creep’. As explained by Davies (1993) [10], a material will experience creep typically in three stages; Primary, Secondary, and Tertiary. During primary creep the rate of strain steadily increases while creep rate decreases then it enters into secondary creep stage. The transition between primary and secondary is observed when strain increases steadily almost linearly which is often difficult to observe. This linear region is secondary creep. In tertiary creep, the rate of strain increases rapidly until ultimate failure. This occurs over a short timeframe. The three stages of creep are illustrated in Fig. 1.

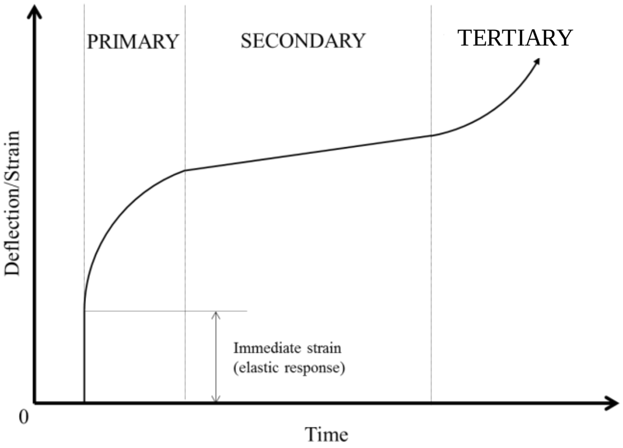

Fig. 1: Typical creep curve.

As depicted by Ramezani and Hamed (2013) [13], when the applied stress is removed, the creep response occurs in three forms, namely, immediate elastic response, recovery and the remaining strain (Fig. 2). The immediate elastic response will be almost instantaneous and then steady which is a sudden retraction of deformation. The recovery phase takes longer and ceases when no more strain is recovered. The final creep strain is the remaining strain that may eventually recover but in most cases does not.

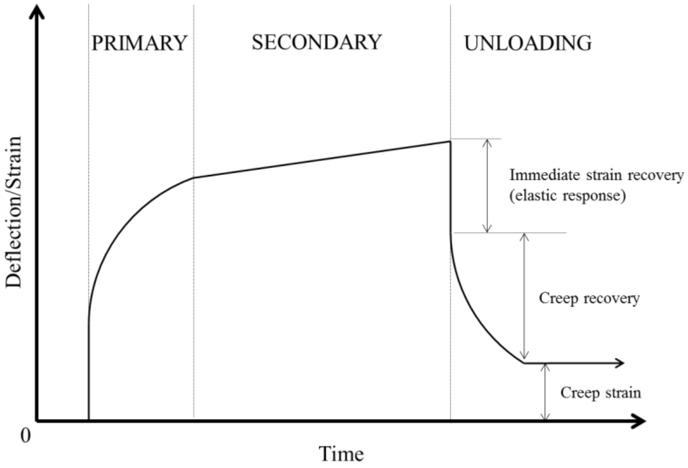

Fig. 2: Creep and creep recovery.

4. Experimental Testing Program

The testing of sandwich panels for flexural creep is detailed in ASTM International C480/480M (2016) [14]. This standard covers the test method for the determination of the creep characteristics of flat sandwich panels for continuous and discontinuous core materials. In this study, three test samples, named A1, A2 and A3, have been used for the testing program (Fig. 3).


Fig. 3: Prepared sandwich panel samples.

Creep testing is carried out based on 3-point load testing configuration according to ASTM International C480/480M (2016) as shown in Fig. 4. ASTM C480 Creep testing for sandwich constructions specifies testing for at least three samples. Therefore, in this study, three samples, named A1, A2 and A3 have been prepared and used in the testing program. The labs temperature has been between 16 to 19 (°C) during the period of testing. Creep testing was conducted on samples A1, A2 and A3, respectively. The samples in the test were under 70% ultimate strength (141kg) with a 3-point loading configuration for the duration of the experiment (Fig.4). Time was recorded along with readings from the deflectometer at midpoint of the sample.

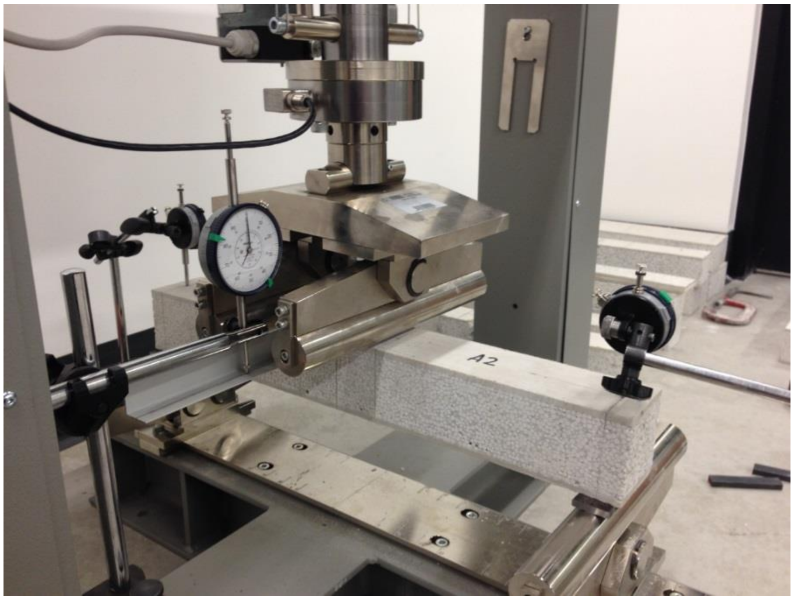

Fig. 4: Final creep testing set up.

Fig. 5 shows creep deflection-time curves of samples A1, A2 and A3, respectively. The final process in the experiment was to gather readings for creep recovery, and also how much of the creep deformations are irrecoverable if any (creep strain). Final readings for the three samples were taken and the unloading process followed. Unloading involved removing the weight plates and noting the gauge reading when the needle had started to steady on the dial gauge (deflectometer).

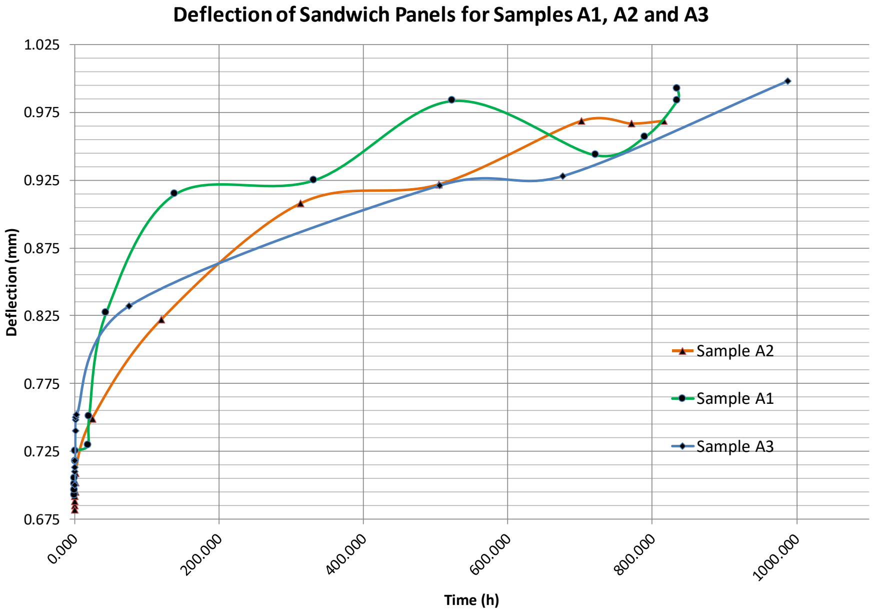

Fig. 5: Creep deflection-time curves of sandwich panels for Samples A1, A2 and A3.

When the weighted plates were removed, the dial gauge needle retracted at a steady rate for a brief moment and then steadied. The steady reading was recorded and the process of removing the load continued until all the load is removed. The experiment entered the creep recovery stage. The three samples were left to slowly recover the deformations caused by the load over a period of one week. Readings were taken during the first few hours and daily until total time had been reached and then all experiments concluded. The creep-recovery test continued from the end of the creep tests mentioned before. The three samples had no load for 7 days for recovery. Fig.6 shows creep recovery deflection-time curves of samples A1, A2 and A3, respectively after unloading the weights.

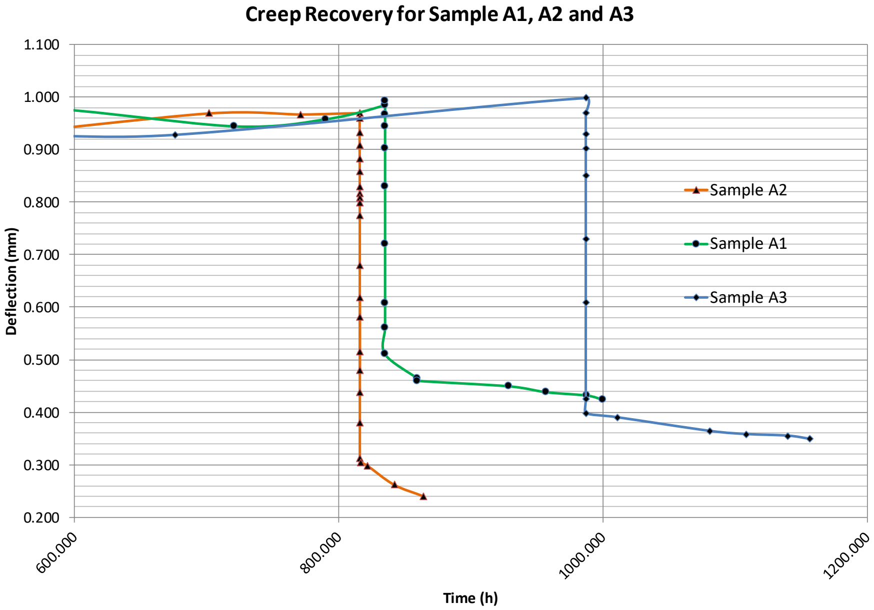

Fig. 6: Creep recovery deflection-time curve of sandwich panel samples A1, A2 and A3.

5. Results and Discussion

The experiments conducted on the sandwich panels produced valuable data for the creep study. In order to have a comprehensive understanding of creep behaviour of the tested sandwich panels, creep curve of average deflection values for the tested samples has been produced and plotted in Fig. 7.

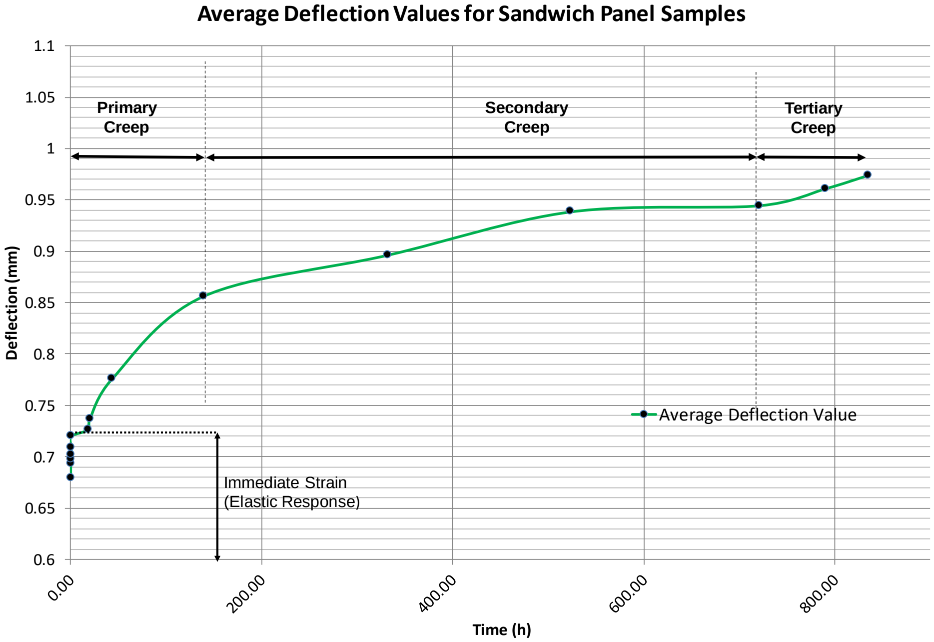

Fig. 7: Typical creep curve of average deflection values for tested sandwich panels.

This plot can replicate creep behaviour of the tested sandwich panel materials with acceptable accuracy as the values have been averaged from three independent tests with exact similar conditions. As shown in Fig. 7, the produced Creep Curve of tested materials has three different stages of the typical creep curve shown in Fig. 1 including primary, secondary and tertiary creep stages. From the produced Creep Curve, the average elastic response of the sandwich panel samples is determined to be 0.725 mm. Having a look to the different creep stages, values for primary, secondary and tertiary creep deflections are 0.135mm, 0.08mm, and 0.04mm showing that as the creep stages increase, creep deflection values reduce. Based on the Creep Curve, the total average creep deflection value for the tested samples is 0.0255mm. It can be understood that creep deflections in average form 26% of the total long term deflection which is more than one-fourth of the total deflection. Hence play a significant role in performance assessment of sandwich panels.

To draw a clear and comprehensive picture on creep recovery of the tested sandwich panels after unloading, average values of creep recovery deflections have been determined and plotted in Fig.8.

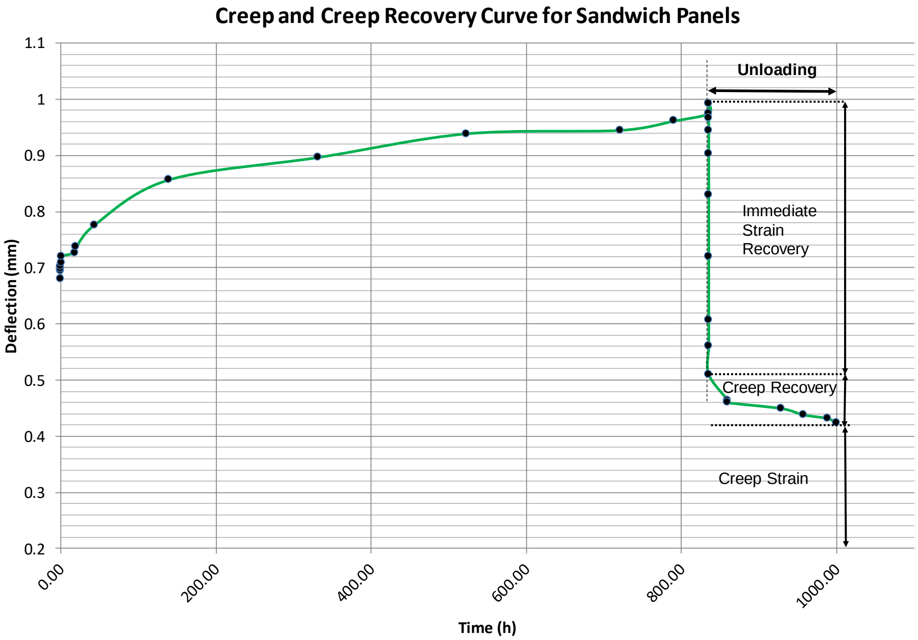

Fig. 8: Typical creep and creep recovery curve of average deflection values for tested sandwich panels.

This plot has both average creep and creep recovery deflection values. The data has been represented over the entire time for clarity. Looking at the plotted data in Fig.8, it is apparent that the Creep Recovery Curve (after unloading) shows immediate strain recovery of 47% while creep strain recovery value is 9%. For the duration of creep recovery, all samples did not fully recover. The amount of deformation that is irrecoverable is the creep strain. As depicted in Fig.2, the creep strain value can be determined from the end of the creep recovery curve. Accordingly, the average creep strain value for the tested sandwich pane samples is 44%. It can be concluded that the amount of the irrecoverable creep strain is noticeably high and has to be determined accurately for structural calculations. The developed and presented Creep Curve and Creep Recovery Curve in this study (Figs. 7 and 8) can be used design curves as well as the suggested values for the creep strain, immediate strain recovery and creep recovery for practical applications in structural engineering.

6. Conclusions

In this study, creep and creep recovery properties of sandwich panels constructed from concrete/polystyrene core and thin cement sheet facings have been investigated. Based on the average deflection results of three test samples, Design Creep Curve (Fig. 7) and Design Creep Recovery Curve (Fig. 8) have been developed and presented for practical applications in structural engineering. Based on the results of this study, it has been understood that creep deflections in average consist 26% of the total long term deflection of sandwich panels. As this is more than one-fourth of the total deflection, it can be understood that creep deflections play a crucial and significant role in performance assessment of sandwich panels constructed of concrete/polystyrene core and thin cement sheet facings.

Based on the creep recovery curve produced in this study, the values for immediate strain recovery and creep strain recovery are 47% and 9%, respectively. In addition, the average creep strain value for the tested sandwich panel samples is 44% which highlights the fact that the amount of the irrecoverable creep strain is noticeably high and has to be determined accurately for structural calculations. Failure to determine the correct irrecoverable creep strain may lead to unrealistic structural design which can potentially threaten the safety and integrity of the structural parts made of sandwich panels constructed of concrete/polystyrene core and thin cement sheet facings.

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