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Structural Sandwich Panels at Low Temperature

Panneaux sandwich à basse température

Sandwichtragelemente bei tiefen Temperaturen

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SUMMARY
Sandwich panels with thin sheet metal faces and a plastic foam core often experience between the faces high temperature gradients which cause deflections and stresses. The mechanical properties of some plastic foams and the design principles for thermal stresses are reviewed in this paper. The magnitude of the stresses due to temperature gradients is presented by examples that are calculated according to the traditional theory of elasticity and also considering the creep of the core.

RÉSUMÉ
Il existe souvent un risque de variation de température entre les surfaces des panneaux sandwichs composés de couches minces ou profilées métalliques avec des noyaux en mousse plastique. Cela cause des déformations et des contraintes dans les panneaux. Cet article analyse des qualités de rigidité de certaines mousses plastiques et explique des principes de calcul pour les contraintes de température. L'intensité des contraintes causées par la variation de température est illustré par des exemples de calcul effectués sur la base de la théorie d'élasticité traditionnelle, en tenant compte de l'effet du fluage du noyau en mousse plastique.

ZUSAMMENFASSUNG
Zwischen den Schichten von Sandwichtragelementen mit Deckschichten aus Stahlfeinblech und Kernschichten aus Schaumstoff entstehen oft hohe Tempreraturdifferenzen, die Verformungen und Spannungen verursachen. In diesem Beitrag werden die mechanischen Eigenschaften von einigen Schaumstoffen und die Berechnungsprinzipien von Tempreraturspannungen vorgestellt. Die Grösse der durch die Temperaturdifferenz verursachten Beanspruchungen wird durch Berechnungsbeispiele veranschaulicht, die nach der traditionellen Elastizitätstheorie gerechnet werden, in denen aber auch das Kriechen der Kernschicht berücksichtigt wird.

1. INTRODUCTION

High and rapid temperature differences occur in sandwich panels with thin metal faces and a plastic foam core because of the good insulative core layer. The differences produce large curvatures to the cross section, and furthermore, deflections and in most cases also stresses to the panel. The stresses depend on the shear stiffness of the core layer, which is usually considered to be a structurally elastic part of the cross section. Most structural foams creep under a long term load and the creeping reduces the shear stiffness of the core and also the thermal stresses of the panel. The creeping of the core can be taken into account by reducing the shear modulus by the well known creep factor. In this case the elastic theory can be still used in the calculations. Influence of the creeping can also be examined more comprehensively by using viscoelastic constitutive laws for the core layer.

Generally the creep rate of structural foams increases with the temperature. In temperatures lower than the room temperature the mechanical properties of the foams are also different. Therefore, it is important in structural desing to evaluate the thermal stresses as accurately as possible and to compare them with the relevant strength values at low temperatures, where the load bearing capacity as well the insulative properties of the panels are actually needed.

To increase the knowledge of the mechanical properties loading tests were carried out with some potential core materials at temperatures +20, -40 and -60 ^{o}C in the Laboratory of Structural Engineering at Technical Research Centre of Finland (VTT). The long term behaviour of sandwich beams with different core materials were studied at room temperature with the facilities of some Finnish companies. To analyse sandwich panels a special purpose program was written, which is based on finite element method and experimental creep functions.

2. MECHANICAL PROPERTIES OF SOME PLASTIC FOAMS

In the experiments there were only a limited number, 3 - 4 pieces, of specimens from each structural foam in each test and at each temperature. The results show that excluding the XPS foam the compressive strengths and moduli slightly increase with the decrease of temperature (Fig. 1). They maintain the shape of their original σ-ε curve, which means that the foams have also high ultimate compressive strain without a tendency to brittleness.

Depending on the material the shear strength increases or decreases slightly at low temperatures, but the strength level remains about the level at +20 ^{o}C. The shear moduli follow the compressive moduli with the temperature. An important property in sandwich panels is also the tensile strength in the flatwise direction of the panel. In the tests this stength was close to its original level at +20 ^{o}C. But by the increase of the tensile moduli the foams became more brittle against the tensile forces.

The long term behaviour of sandwich beams with different core materials were studied only at room temperature. The nonlinearity in the long term creep function was examined by changing the shear stress level in the core (Fig. 2). All the stress levels were above the long term design stress level in usual structures, where the highest stress at the serviceability limit state is about 40 % of the characteristic short term strength. The test results of EPS foam show clearly nonlinearity above the stress level 0.4-times the characteristic short term strength. The design stresses have to be kept in the stable area below this stress limit. All the creep functions of the PIR foams have about the same shape, only their level is increasing slightly with the shear stress. The latter result follows from the low shear strength of the joint between polyisocyanurate foam and steel face, for which reason the shear strength of the foam itself ...uld not be totally utilized.

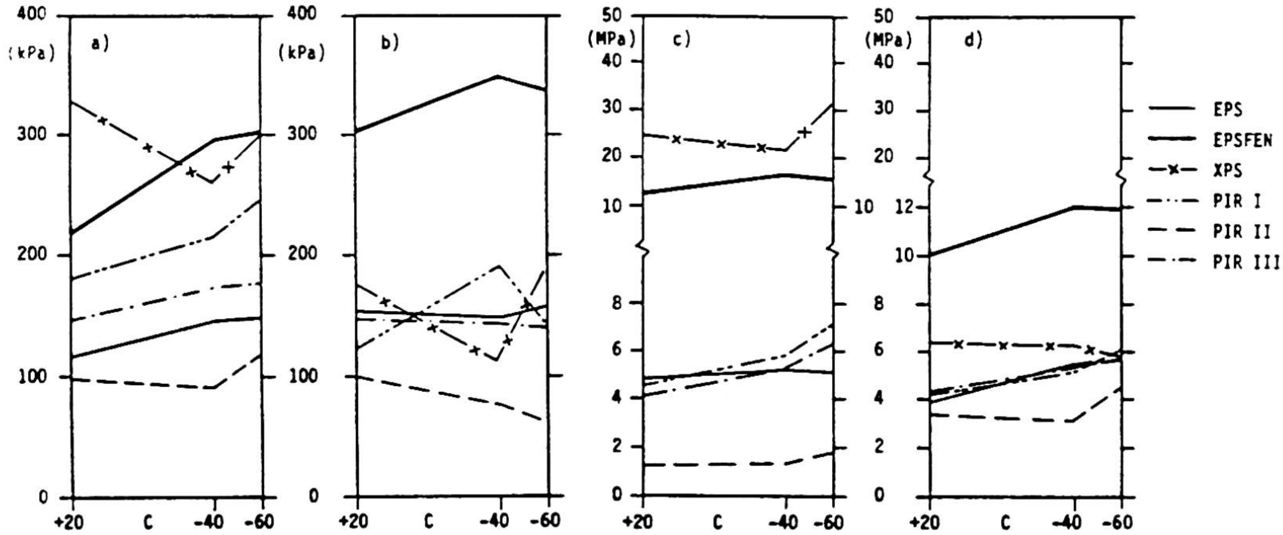

Fig. 1. a) Characteristic compressive and b) shear strengths and c) characteristic compressive and d) shear moduli of polystyrene, EPS ($\bar{\rho}$ = 19.5 kg/m^3), phenol filled polystyrene, EPSFEN ($\bar{\rho}$ = 40.8 kg/m^3), extruded polystyrene, XPS ($\bar{\rho}$ = ?2 kg/m^3), polyisocyanurate, PIR I ($\bar{\rho}$ = 42.5 kg/m^3, batch mould), PIR II ($\bar{\rho}$ = 40.6 kg/m^3, continuous laminator), PIR III ($\bar{\rho}$ = 38.2 kg/m^3, continuous laminator).

The creep curves in literature show that the creeping becomes slower at low temperatures /1/. The following creep function, determined at room remperature, is suitable to describe the creep of commonly used core materials

$$J(t) = \frac{1}{G} + J_1\ t^n \tag{1}$$

where G denotes the short term shear modulus and J_1 and n are parameters. t is the time.

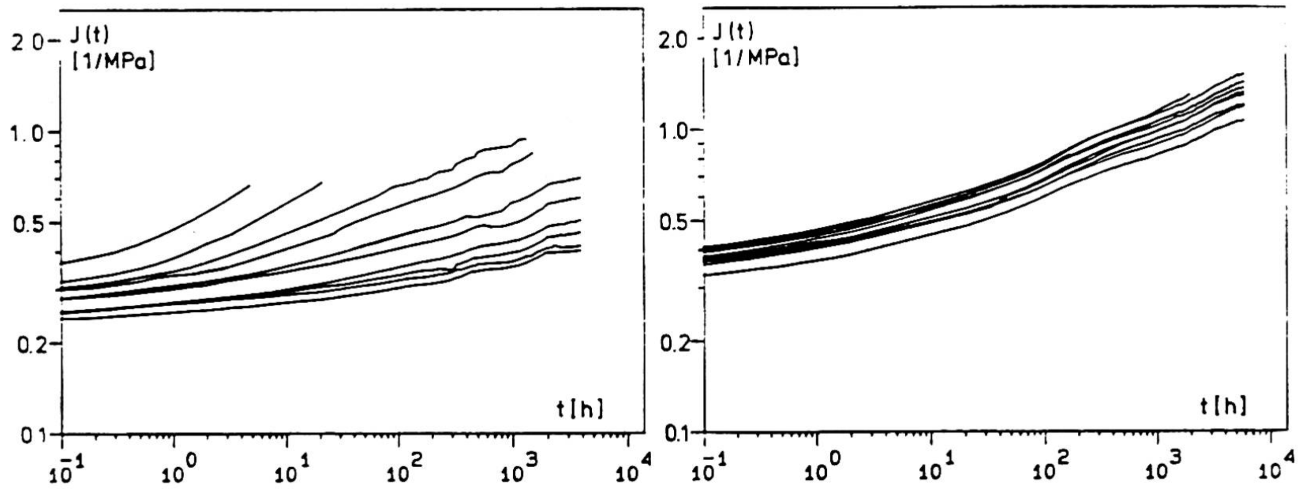

Fig. 2. Shear creep functions of a) an expanded polystyrene (τ_{ko} = 145 kPa) and b) a polyisocyanurate (τ_{ko} = 70 kPa) foam determined in beam tests. The foams are the same as EPS and PIR II in Fig. 1. The stress level of the functions is 0.4, 0.5, 0.6, 0.7 or 0.8 τ_{ko}. τ_{ko} represents the characteristic short term shear strength at temperature +20 ^{o}C. In the figures curves of two specimens have been drawn at each stress level.

3. THERMAL STRESSES IN SANDWICH PANELS

3.1 Analysis of sandwich panels

The finite element solution of sandwich beams with thick or profiled face layers is based on the following homogenous differential equations.

$$
\begin{aligned}
w^{(6)} - \left(\frac{\lambda}{L}\right)^2 w^{(4)} &= 0 \\
\gamma^{(4)} - \left(\frac{\lambda}{L}\right)^2 \gamma^{(2)} &= 0
\end{aligned}
\qquad (2)
$$

where w is the deflection, γ the shear strain in core, primes denote differentation with respect to x that is directed along the axis of the panel. L is the length of the panel. The thick-wallness parameter λ is given by

$$\lambda^2 = \frac{BSL^2}{B_S B_D} \qquad (3)$$

where B_D and B_S are the bending stiffnesses of the faces alone and due to the sandwich action. B is the total stiffness of the cross-section, $B = B_D + B_S$. S is the shear stiffness of core S = GA, where A is the effective shear area and G the shear modulus.

Using the solutions of the equations (2) and the linear elastic relation between the strains and stresses and further the equation of equilibrium M' = Q equation (4) can be written for a finite element.

$$\{F\} = [K]\{d\} \qquad (4)$$

The equations (2) are also valid in the case of a viscoelastic core provided that the shear modulus G is replaced with timedependent "secant modulus" G_S, that is the ratio of the shear stress and the shear strain γ. In the finite element formulation G_S is assumed to be constant in an element.

In the viscoelastic case the displacements are obtained by time integration. Assuming the state at time t_1 known and the load constant in the interval from t_1 to t_2 the displacement at t_2 can be iterated from the equation

$$[K]_1\{d\}_2^{n+1} = \{F\} - ([K]_2^n - [K]_1)\ \{d\}_2^n \qquad (5)$$

where $\{F\}$ is the loadvector and the subscripts 1 and 2 refer to times t_1 and t_2 and the superscripts denote the iteration cycles.

Practically the same results as by the viscoelastic finite element method can be found in linear viscoelastic cases by replacing the shear modulus by a time dependent shear modulus G(t) = 1/J(t) in the elastic analysis. However, the calculations of structures caused by variable loads are very laborious. The viscoelastic finite element analysis is the only possibility, if the second order effects caused by the axial loads or the stress dependent creep functions are to be included in the analysis.

3.2 Examples

In the first example a thin faced two span sandwich panel is exposed to a temperature gradient of 80 ^{o}C. In the first loading case the temperature difference

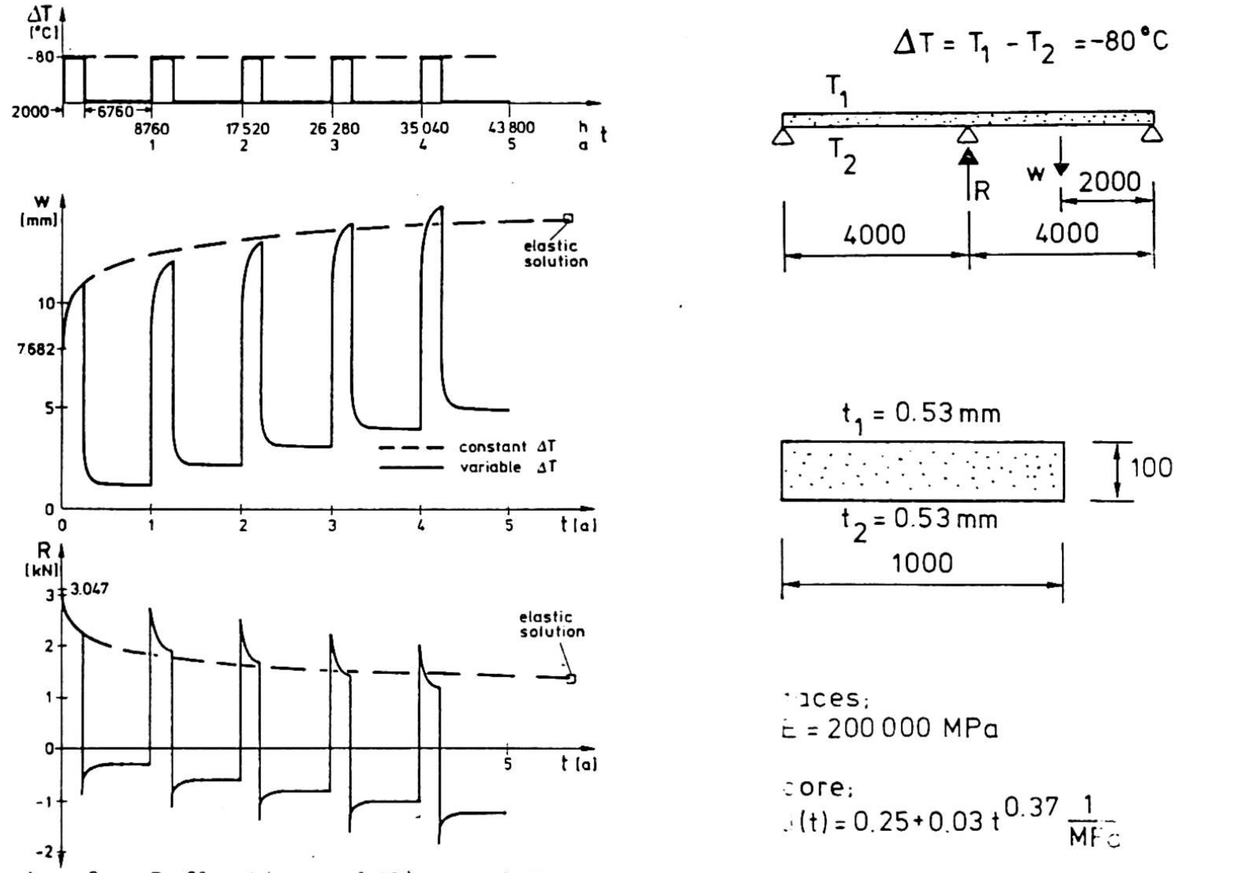

Fig. 3. Deflection w(l/2) and interme[illegible]t reaction R of a [illegible] sandwich beam caused by a con[illegible]riable temperature difference of -80 °C between the faces.

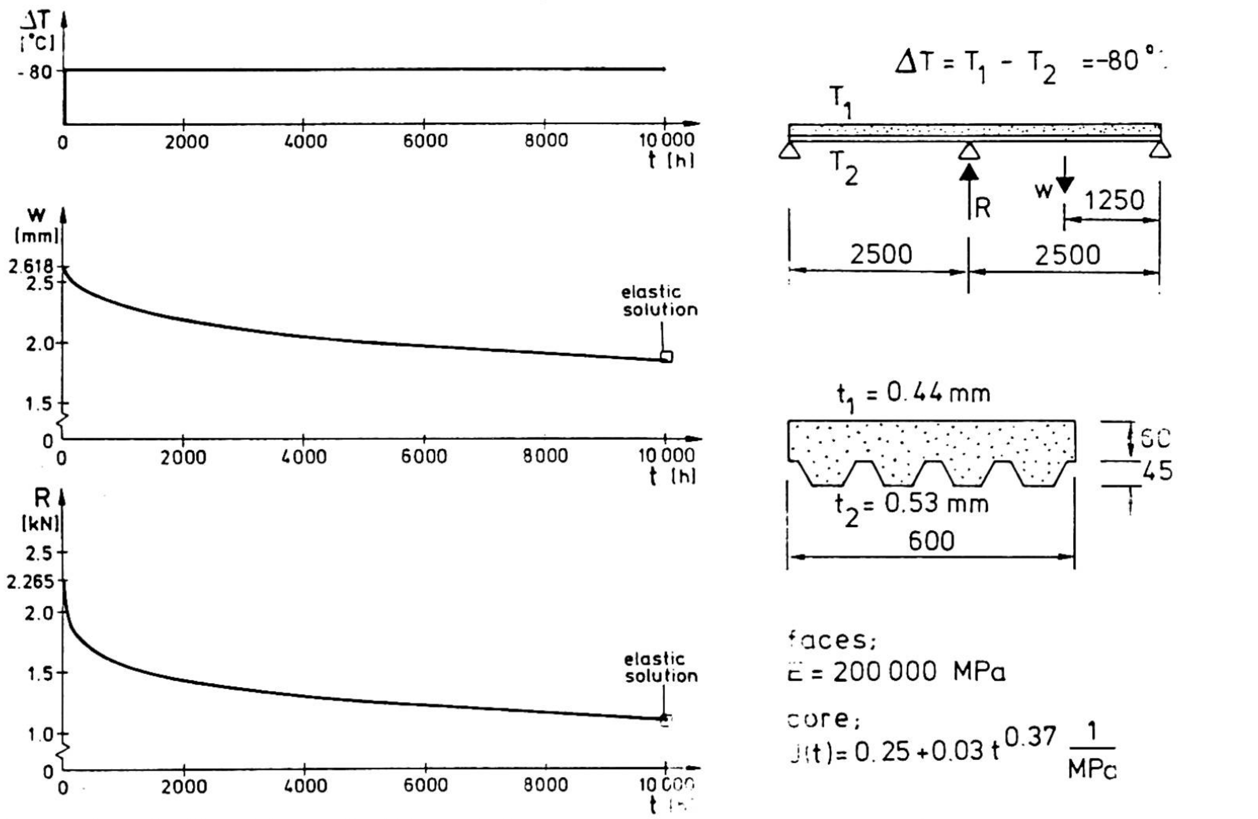

Fig. 4. Deflection w(l/2) and intermediate support reaction R of a profiled faced sandwich beam caused by a constant temperature difference of -80 °C.

is constant over five years and in the second one the thermal load acts 2000 hours in a year (Fig. 3). To the viscoelastic core layer the creep function (1) is used where the shear modulus G and the parameters J_1 and n have the values 4.0 MPa, 0.03 1/MPa and 0.37.

Under a constant temperature gradient the deflections increase and the stresses e.g. support reactions decrease monotonously being delayed. Under the variable thermal load deflections increase faster than in the case of constant load. The stresses get considerable negative values in the unloading phase.

The lower face in the sandwich panel of the second example is profiled. This two span beam is exposed only to a constant temperature difference of -80 ^{0}C. Both the deflections and the stresses of thick faced sandwich beam decrease due to the creep of the core because of the bending stiff face. So the change of the deflections is contrary to those of the thin faced sandwich beam in the first example. The theory of elasticity with reduced shear modulus $G(t) = 1/J(t)$ gives the same results.

4. CONCLUSIONS

The thermal stresses are a significant loading case in the design of sandwich panels. The core material has to be capable to carry the shear stresses and to support the faces against the buckling stresses caused by the own weight, snow and wind loads and further by the temperature difference between the faces over the whole existing temperature. The experiments show, that the most commonly used core materials preserve their mechanical properties up to a temperature of -60 ^{0}C. Nevertheless, the change of strength and modulus values depends on the initial structure of the foam. By many foams a low density indicates also poor strength that is emphasized at low temperatures.

The creep of a viscoelastic core layer diminishes effectively thermal stresses and this is profitable in the design of sandwich structures. However, at low temperatures the creeping proceeds somewhat slower than at room temperature and considerably slower than at high temperatures. Thus the influence of temperature to the reduction of thermal stresses has to be taken into account in foam cored sandwich panels.

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