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DESIGN MAP OF SANDWICH BEAMS LOADED IN THREE-POINT BENDING

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Abstract: *Design map for sandwich beam with composite face sheets loaded in three-point bending is presented. This map may be helpful in choosing an optimal configuration to achieve a sandwich material. In this paper the failure mode map was constructed based on analytical procedures and the results were validated by experimental tests. Three-point bending tests were performed for some sandwich specimens with aluminium faces and cork core and the results (core shear) showed a good agreement with analytical predictions.*
Key words: *Design map, sandwich beam, failure mode*

1. INTRODUCTION

Structural members made up of two stiff, strong skins separated by a lightweight core are known as sandwich panels. The mechanical behavior of a sandwich panel depends on the properties of the face and core materials and on its geometry. In most applications the panel must have some required minimum stiffness, it must not fail under some maximum service loading and it must be as light as possible (Gibson et al., 1997).

The obvious attraction of sandwich structures is that they are light and stiff. The beam or panel must also have strength: it must carry the design loads without failing. At least five different failure modes are possible; a given sandwich will fail by the one which occurs at the lowest load, (Andrews et al., 2009), (Triantafillou et al., 1987), (Ley et al., 1999). With changing the geometry and loading the failure mode can change, too. So it is not enough to design against one mode; all must be considered, and the dominant mode – the one which determines failure – identified and evaluated.

In most cases, for sandwich beams loaded in three-point bending, the following failure modes can occurs, Fig. 1:

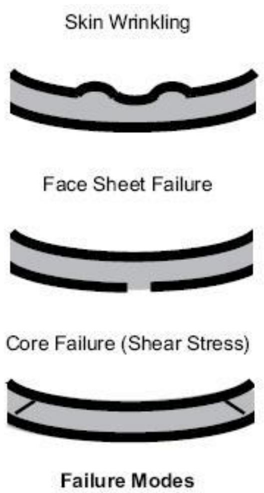


Fig. 1. Failure modes of sandwich beams

The dominant mechanism, for a given design, is the one giving failure at the lowest critical load. A transition in failure mechanism takes place when two mechanisms have the same failure load. This information can be displayed as a diagram or map, Fig. 2. The diagram is divided into fields, within which one failure mechanism is dominant. The fields are separated by field boundaries, which are the loci of design points for which two mechanisms have the same failure load.

Based on previous considerations, in this paper we determined a designed map for sandwich beam with aluminium faces and cork core loaded in three-point bending such in figure 3.

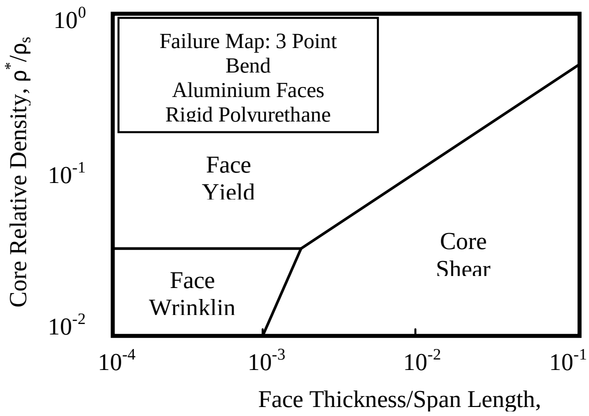
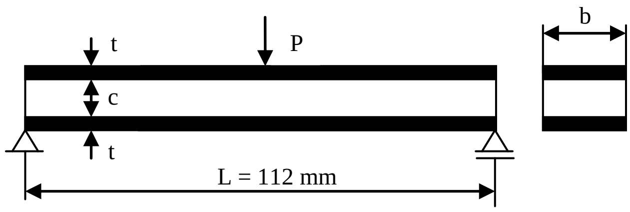


Fig. 2. Example of failure map of a sandwich panels with aluminium faces and foam core



b = 12 mm; c = 5 mm; t = 1.5 mm

Fig. 3. Sandwich beam with aluminium faces and cork core in three-point bending

2. DESIGN MAP OF A SANDWICH BEAM LOADED IN THREE-POINT BENDING

Applying the strength theory of sandwich beams we calculated that the critical stress and force for every failure mode, for different face thickness values and different cork densities, Fig. 4 and Tabel 1.

Face Sheet failure, occurs when the normal stress in the face equals the strength of the face material, σ_{yf}, or when:

$$\sigma_f = \frac{Pl}{B_3 b} = \sigma_{yf} \tag{1}$$

Face wrinkling appears when the normal stress in the compressive face of the beam reaches the local instability stress. Wrinkling occurs when the compressive stress in the face is:

$$\sigma_f = \frac{Pl}{B_3 btc} = \frac{3E_f^{1/3}E_c^{*2/3}}{[12(3-\vartheta_c^*)^2(1+\vartheta_c^*)^{1/3}]} \tag{2}$$

Core shear failure, when the shear stress, τ_c, equals the yield strength of the core in shear, τ_C^*:

$$\tau_C = \tau_C^* \qquad (3)$$

The yield strength of the core in shear depends on density in the same way as the uniaxial strength.

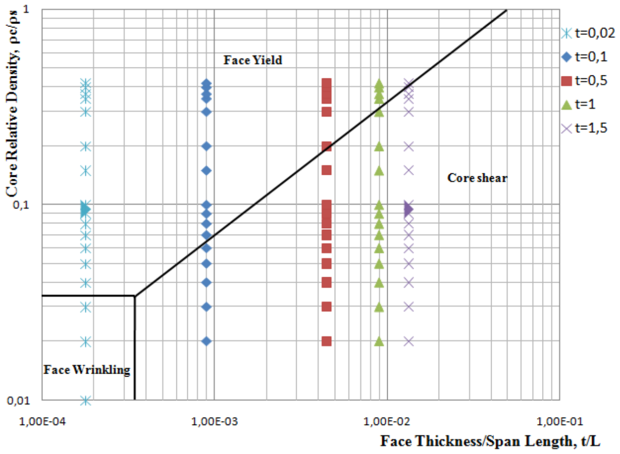


Fig. 4. Design map of sandwich beams loaded in three-point bending

3. EXPERIMENTAL ANALYSIS OF THE SANDWICH BEAM LOADED IN THREE-POINT BENDING

The three-point bending tests were performed on tensile testing machine, model Zwick/Roell 5 kN, fig. 5, using specimens with dimensions from figure 3. Tests were carried out according with ASTM D 790-03 at a loading rate of 2 mm/min and at room temperature.

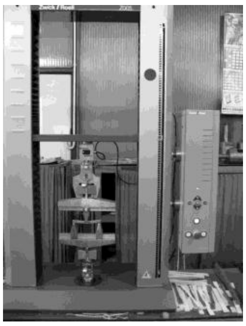


Fig. 5. The Zwick/Roell testing machine

Five samples were tested and the results showed a failure load between 40 and 60 N for a core relative density equal with 0.15. The tests showed that the dominant failure mechanism of the tested sandwich beams in three-point bending is the cork core shear, Fig.6.

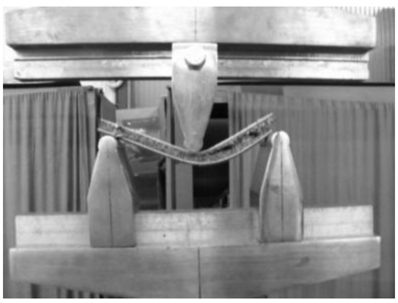


Fig. 6. Failure mode of a sandwich beam loaded in three-point bending

CRD	Analitical procedure									
	t=0,02		t=0,1		t=0,5		t=1		t=1,5	
	P[N]	FM	P[N]	FM	P[N]	FM	P[N]	FM	P[N]	FM
0,01	0,77	FW								
0,02	1,85	FW	3,07	CS	2,71	CS	2,71	CS	2,71	CS
0,03	3,24	FW	5,09	CS	5,09	CS	5,09	CS	5,09	CS
0,04	3,3	FY	7,68	CS	7,68	CS	7,68	CS	7,68	CS
0,05	3,3	FY	10,5	CS	10,5	CS	10,5	CS	10,5	CS
0,06	3,3	FY	14,1	CS	14,1	CS	14,1	CS	14,1	CS
0,07	3,3	FY	16,5	FY	17,9	CS	17,9	CS	17,9	CS
0,08	3,3	FY	16,5	FY	21,7	CS	21,7	CS	21,7	CS
0,09	3,3	FY	16,5	FY	25,7	CS	25,7	CS	25,7	CS
0,1	3,3	FY	16,5	FY	30,3	CS	30,3	CS	30,3	CS
0,15	3,3	FY	16,5	FY	56	CS	56	CS	56	CS
0,2	3,3	FY	16,5	FY	82,5	FY	82,5	CS	82,5	CS
0,3	3,3	FY	16,5	FY	82,5	FY	157,7	CS	157,7	CS
0,35	3,3	FY	16,5	FY	82,5	FY	165	FY	198,4	CS
0,37	3,3	FY	16,5	FY	82,5	FY	165	FY	216,4	CS
0,4	3,3	FY	16,5	FY	82,5	FY	165	FY	242,8	CS

Tab.1. The critical force values of sandwich beams loaded in three-point bending

CRD – Core Relative Density; FM – Failure Mode; FW – Face wrinkling; FY – Face Yield; CS – Core Shear

4. CONCLUSION

This paper presents failure and design mode map for sandwich beams with cork core and aluminium faces used in some applications of railway vehicle. This design diagram provides information about the failure mode and critical forces (Tabel 1) of sandwich beams based on core density and dimensions of the analysed specimen (beam or panel). The failure mode observed on the tested sandwich beams was cork core shear (fig. 6) and was in agreement with the failure mode predicted from designed map, Fig. 4.

5. ACKNOWLEDGEMENTS

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