

PROCEEDINGS

inter·noise 97

BUDAPEST



HUNGARY

1997 AUGUST 25-27

HELP QUIET
THE WORLD FOR A HIGHER QUALITY LIFE

Volume I Volume II Volume III

editor: Fülöp Augusztinovicz

inter-noise 97

Budapest – Hungary, August 25-27

STATIC STIFFNESS AND VIBRATION DAMPING OF SANDWICH BEAMS CONTAINING RUBBER AND FIBER-REINFORCED PLASTIC LAYERS

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1. INTRODUCTION

In our previous research [1] we have studied the static and dynamic behaviour of a special three-layer sandwich beam consisting of two aluminium square tubes and a rubber layer glued between them. This study has shown that the poor damping capacity of aluminium beams can be improved by using a rubber layer. The disadvantage of such sandwich beams was the relatively high dynamic deflection due to the shear deformation of the rubber layer. For the present study our aim was to decrease this large deflection by using fiber-reinforced plastic (FRP) layers. To investigate the static and dynamic behaviour of sandwich beams constructed from aluminium square hollow section (SHS) and rubber and FRP layers, we have used 3 specimens as shown in Fig.1. Static bending tests and vibration damping measurements serve to describe the most important characteristics of the investigated models. For the calculations the static and dynamic bending theory of sandwich beams with thick faces is applied.

2. STATIC TESTS

In the static tests the maximum deflection is measured at the midspan of simply supported beams loaded by a concentrated force at midspan. Three specimens have been manufactured and tested (Fig.1).

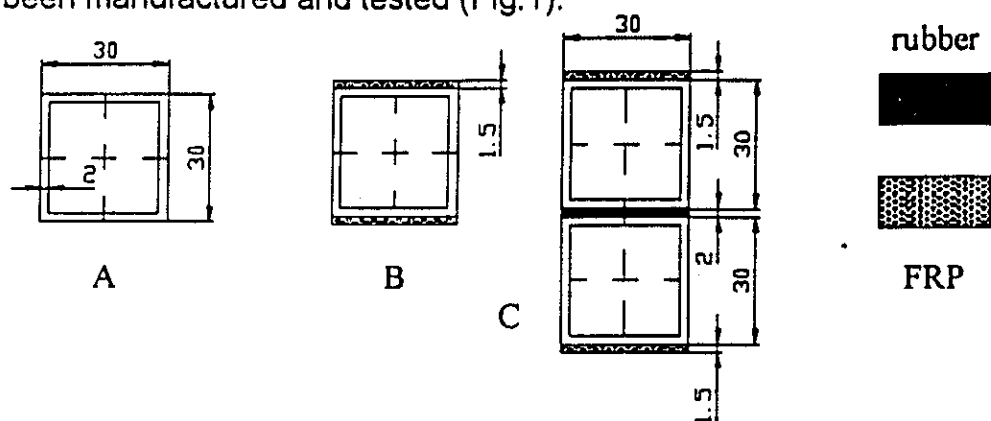


Fig. 1. Tested specimens

2.1. Specimen A

An aluminium alloy SHS beam of dimensions 30*2 mm and span length $L=1800$ mm is used. All other specimens contain aluminium SHS bars with these dimensions. The cross-sectional area is $A = 216 \text{ mm}^2$, the moment of inertia is

$I_x = 26400 \text{ mm}^4$, the modulus of elasticity is $E = 7 \cdot 10^4 \text{ MPa}$, the maximum deflection for a force $F = 330 \text{ N}$ is $w_{max} = FL^3/(48EI_x) = 21.7 \text{ mm}$, which agrees with the measured value of 20 mm.

2.2. Specimen B

This specimen has two FRP layers glued on the SHS profile. The characteristics of the FRP layers are as follows. The modulus of elasticity along the fiber direction is [2] $E_L = E_f V_f/V + E_m V_m/V$, where the subscripts f and m relate to the fibers and matrix, respectively. The FRP layers used in our experiments have glass fibers and the volume fraction of fibers in longitudinal direction is 75% and in transverse one 25%. In a 0.15 mm thick layer of 1 mm² area the volume of fibers is $V_f = 0.70 \cdot 0.15 = 0.105 \text{ mm}^3$ and that of matrix $V_m = 0.30 \cdot 0.15 = 0.045 \text{ mm}^3$. Thus

$$\frac{V_f}{V} = \frac{0.105 \cdot 0.75}{0.105 \cdot 0.75 + 0.045} = 0.6364, \quad \frac{V_m}{V} = 0.3636 \text{ and}$$

$$E_L = 71000 \cdot 0.6364 + 2200 \cdot 0.3636 = 45984 \text{ MPa.}$$

One FRP reinforcement contains 7 layers with the fiber orientation angles as follows: for 75% 0° , for 25% 90° . The reduced bending stiffness of the specimen B is calculated as $(EI)_{red} = E_A I_A + E_L I_C$, where the subscripts A and C relate to aluminium and composite, respectively. The manufactured thickness of the composite layer (FRP reinforcement) is $t_c = 1.5 \text{ mm}$,

$$I_C = 2bt_c \left(\frac{b+t_c}{2} \right)^2 = 22326 \text{ mm}^4, \quad (EI)_{red} = 2.874 \cdot 10^9 \text{ Nmm}^2.$$

The maximum deflection due to a concentric force 210 N acting at midspan of a simply supported beam of span length 1850 mm is $w_{max} = FL^3/[48(EI)_{red}] = 9.64 \text{ mm}$, the measured deflection was 9.88 mm, the agreement is good.

2.3. Specimen C

This beam is constructed from two SHS profiles, a rubber layer glued between them and two FRP layers glued on the upper and lower flanges. The deflection should be calculated according to the theory of sandwich beams with thick faces, developed e.g. in [3] (also in [4]), which considers also the shear deformation of the core. Here we consider the reduced stiffness of SHS and FRP layers as faces.

$$w_{max} = \frac{FL^3}{48B} + \frac{FL}{4B_q} \left(1 - \frac{B_f}{B} \right)^2 \left(1 - \frac{\tanh \chi}{\chi} \right)$$

where $\chi = \frac{1}{2} \left[\frac{B_f}{B_q L^2} \left(1 - \frac{B_f}{B} \right) \right]^{-1/2}$ $B = B_f + B_s$; $B_f = 2(EI)_{red}$

$$B_s = 2 \sum_i E_i A_i e_i^2 \quad B_q = G_s b (h + t_2)^2 / t_2$$

$G_s = 1.5$ MPa being the static shear modulus of the rubber, $b = h = 30$, $t_2 = 2$ mm. $B_q = 23040$, $B_r = 3.696 \cdot 10^9$, $B_s = 1.048 \cdot 10^{10}$, $B = 1.4176 \cdot 10^{10}$ Nmm², $\chi = 2.6134$, $w_{max} = 25.3$ mm, which agrees well with the measured 22 mm. The deflections are summarized in Table 1 unified for a force 100 N and span length of 1800 mm.

Table 1. Deflections due to a force of 100 N

Specimen	A	B	C	D
Deflection (mm)	6.57	4.23	1.77	1.16

The difference of 35% between deflections for specimens A and B shows how the FRP layers increase the static bending stiffness of the SHS beam. For comparison we have calculated the deflection for a specimen D that means two SHS profiles rigidly connected to each other without any layers. It can be seen that the shear deformation of the soft rubber layer increases the deflection from 1.16 to 1.77 mm i.e. decreases the bending stiffness by 52%.

3. VIBRATION MEASUREMENTS

In order to determine the eigenfrequencies and vibration damping or loss factors the Brüel-Kjaer vibration measuring devices have been used in our laboratory. The loss factors are obtained by using the half-power bandwidth method. The formula for the loss factor at the i th eigenfrequency f_i is $\eta_i = \Delta f / f_i$, where Δf is the frequency bandwidth. Table 2 gives the measured results.

Table 2. Measurement results: eigenfrequencies and loss factors

Specimen	A			B			C		
	1	2	3	1	2	3	1	2	3
f_i (Hz)	32	196	536	33	200	543	52	255	648
η_i	0.0125	0.0028	0.0015	0.012	0.0032	0.0028	0.052	0.057	0.053

Remarks to the data: specimen A: the material damping of aluminium profile is very low. Specimens B: the FRP layers do not increase the damping capacity of SHS beams, since the damping of individual FRP layers is also low. Specimen C: The rubber layer at the neutral axis causes a significant increase of the loss factor due to the shear damping, compared to specimen A the loss factor is quadrupled. This loss factor can be calculated using the formula for sandwich beams with thick faces developed in [5] (also in [4])

$$\eta = \frac{\eta_2 XY}{1 + (2 + Y)X + (1 + Y)(1 + \eta_2^2)X^2}$$

$$\text{where } X = g_0 \left(\frac{C_d L}{2\pi} \right)^2 \quad g_0 = \frac{2G_d b}{t_2 \sum A_i E_i} \quad Y = \frac{(b + t_2)^2}{2B_f} \sum A_i E_i$$

For rubber $G_d = 4.5 \text{ MPa}$, according to [6] $C_d = 1.1$, $L = 1800 \text{ mm}$. $X = 0.8125$, $g_0 = 8.1818 \cdot 10^{-6} \text{ mm}^2$, $Y = 2.2857$, $\eta = 0.0497$. This value is near to the measured ones.

4. CONCLUSIONS

The static bending stiffness of a SHS aluminium beam can be significantly increased by using FRP layers. This increase was in the case of our investigated specimens about 35%, without any increase in weight. The FRP layers do not increase the vibration damping, the loss factor is only about 1%. The static behaviour of a SHS profile with FRP layers can be calculated by the reduced bending stiffness. The damping can be significantly increased by applying a rubber layer of high damping capacity. In our case the loss factor has been quadrupled (comparison between specimens A and C). Due to a soft rubber layer the static bending stiffness decreased by 52%. The static and dynamic behaviour of specimen C can be calculated with sufficient accuracy by the bending theory of sandwich beams with thick faces [7,8].

ACKNOWLEDGEMENTS

This work has been supported by the Hungarian Fund for Scientific Research grants OTKA T-19003 and T-22846.

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