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Measurements of the effective stiffness of the sealing system

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No. of ARRS project: L2-3172

ARRS project title: Development of technical guidelines for quadruple glazing

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Ljubljana, September 2022

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Financial support:	The project is financially supported by the Slovenian Research Agency ARRS (research project No. L2-3172) and the company Reflex d.o.o.
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ARRS project title:	Development of technical guidelines for quadruple glazing
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1. Problem description

To model the mechanical response of multipane glazing panels which are exposed to temperature and environmental changes, we must model not only the individual glass panes but also the sealing system which seals up the individual panel chambers. The assembly of a typical sealing system is shown in Fig. 1. The sealing system is composed of layers of primary seals, a spacer, and a secondary sealant. All elements of the sealing system contribute to the mechanical load transfer between individual glass sheets. To model this behavior as realistically as possible, we opted to measure the effective stiffness of the whole sealing system, and consequently include it in the numerical model as a whole assembly (as opposed to modeling all the individual sealing system components).

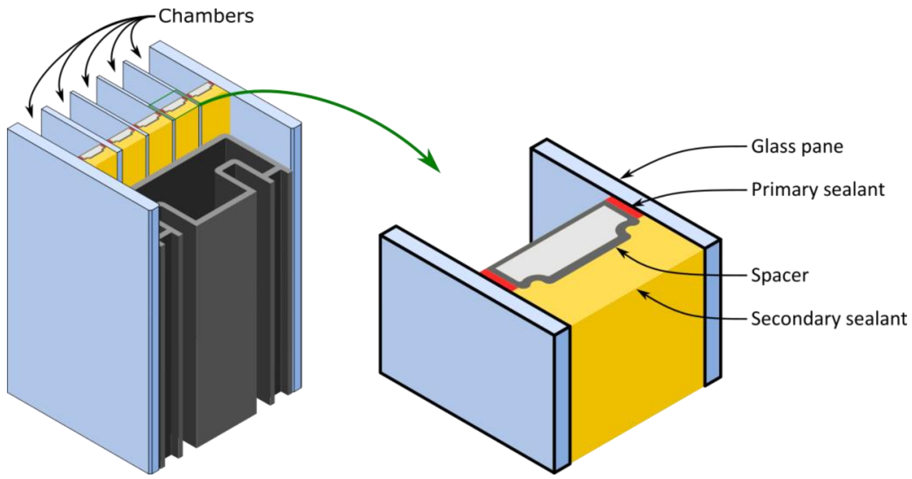


Figure 1: Assembly of a typical sealing system.

The manufacturer of glazing panels prepared test samples of the sealing system shown in Fig. 2. In practice, different combinations of spacers and thicknesses of the secondary sealant are used. Therefore, we prepared and measured different configurations of the sealing system as summarized in Table 1.

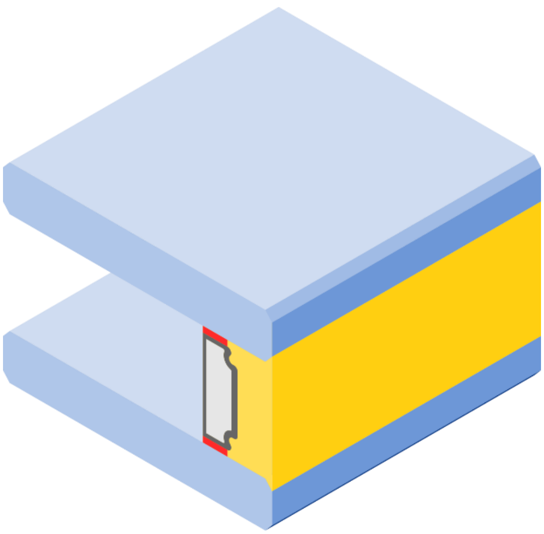


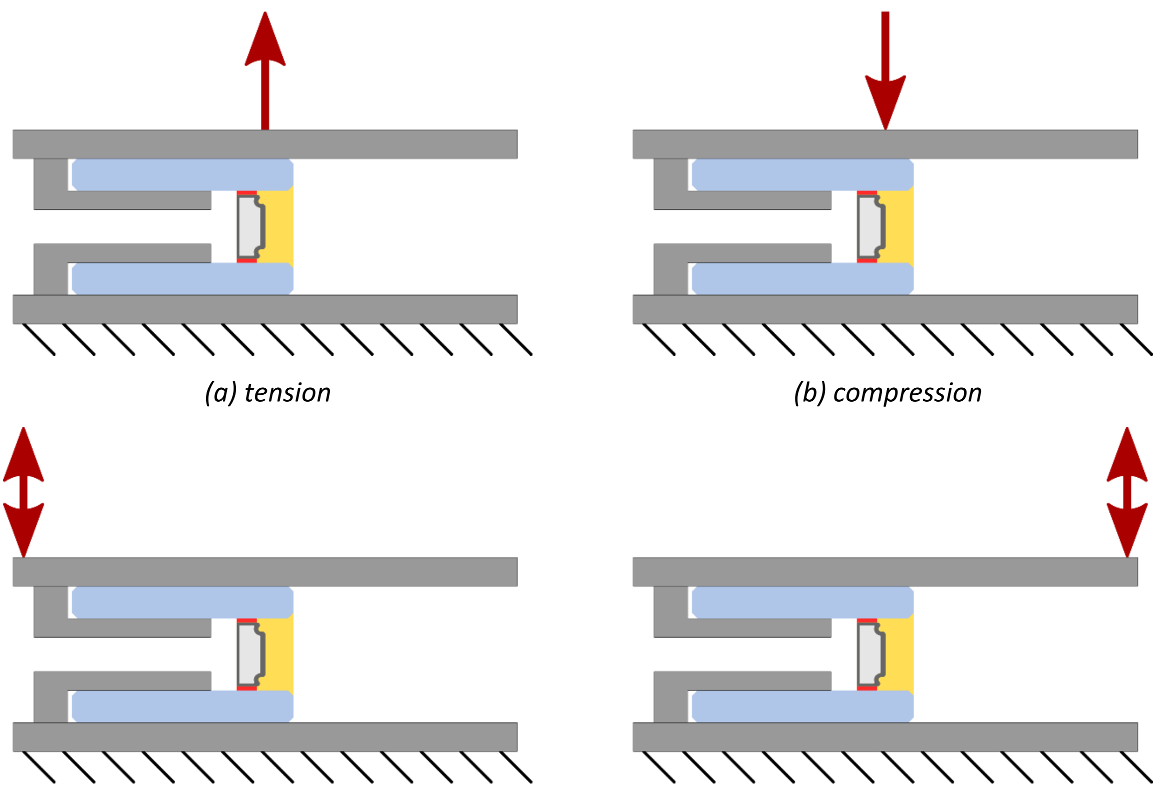
Figure 2: Test samples of the sealing system.

Table 1: *Measured configurations of the sealing system.*

ID	Spacer type	Spacer height (mm)	Secondary seal thickness (mm)
A	Metal + polymer	12	5
B	Metal + polymer	18	5
C	Metal + polymer	18	7
D	Foam + foil	18	5

2. Measurement setup

To measure all configurations of the sealing system in different load case scenarios, we designed a special clamping adapter which was used in the universal testing machine. The clamping adapter enables us to measure the mechanical response of the sealing system when subjected to tension, compression, or bending in different orientations as shown in Fig. 3.



(a) tension *(b) compression*

(c) bending 1st orientation *(d) bending 2nd orientation*

Figure 3: Measurement setups for different load cases.

Using the special clamping adapter, the test samples were loaded with a universal tensile testing machine (LNMS TM1). Force was measured with the AEP TC4 micro 1kN load cell. Displacements and rotations were measured directly on the specimen's front surface using an optical measurement system based on the digital image correlation (DIC) using the Dantec Dynamics Q-400 setup. The DIC system used two 5 MPx cameras as shown in Fig. 4.

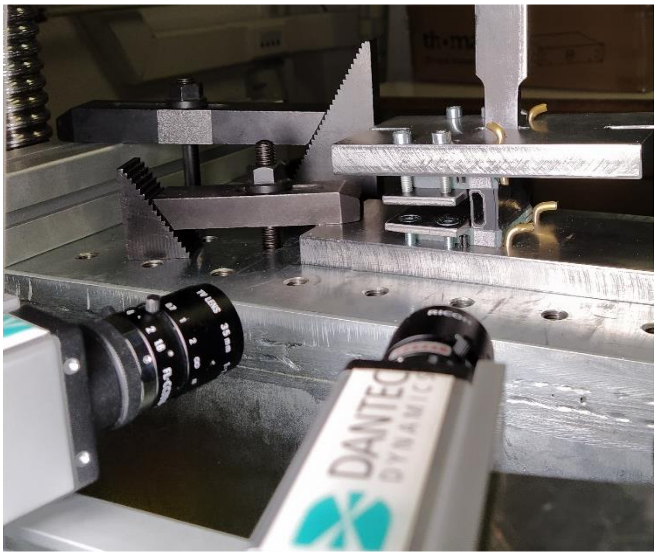


Figure 4: Measurement setup – measurement of the displacements and rotations.

3. Results

The measured mechanical responses of the sealing system to the tensile, compression, and two bending loads are shown in Figs. 5 – 8. Please note that the plots show only a short first section of the responses. Responses at larger deformations are not shown as we are interested only in the initial (linear) stiffness of the sealing system. The results reveal some scatter, which we can correlate mainly to the imperfectly made samples (e.g. the secondary sealant layer varies in thickness between the samples).

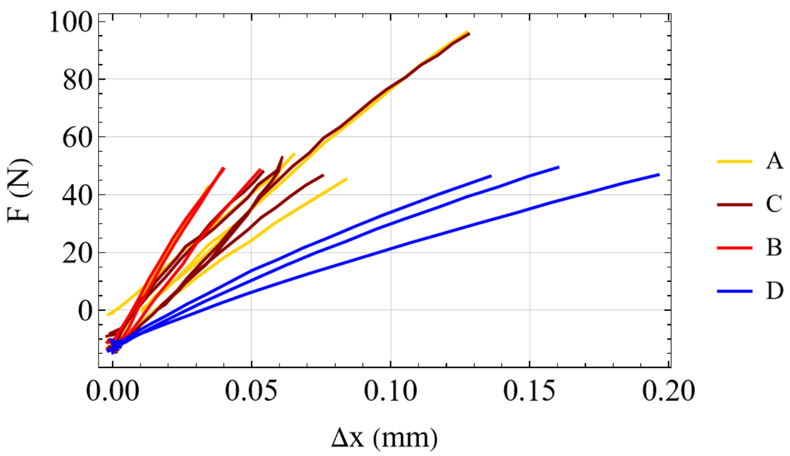


Figure 5: Measured tension response of the sealing system.

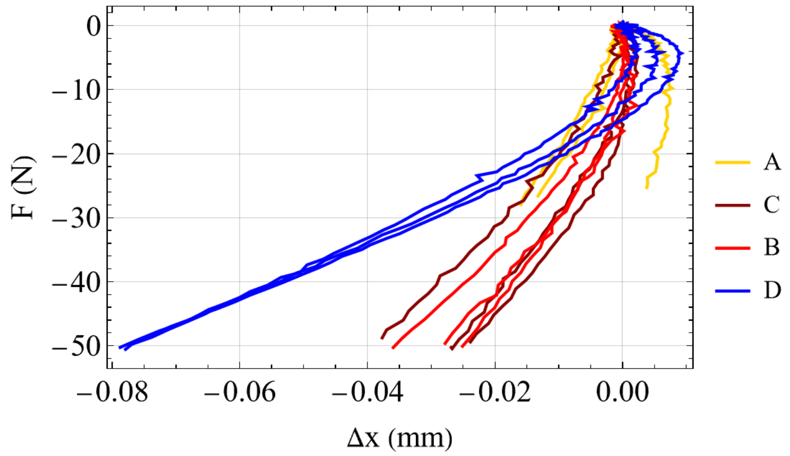


Figure 6: Measured compression response of the sealing system.

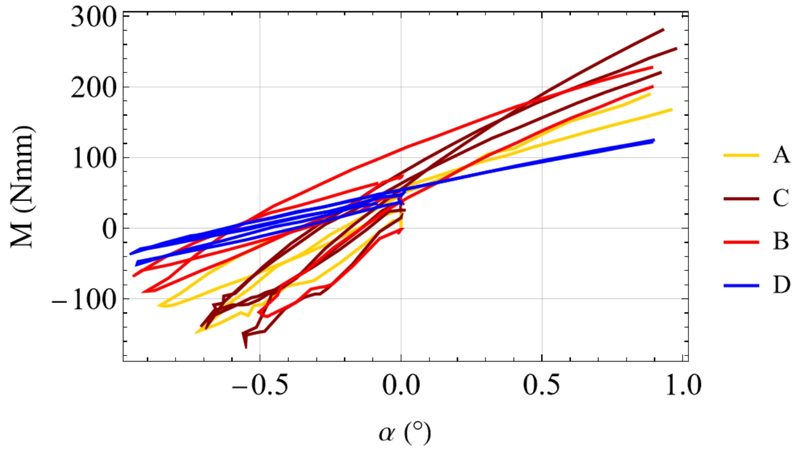


Figure 7: Measured bending response in the 1st orientation of the sealing system.

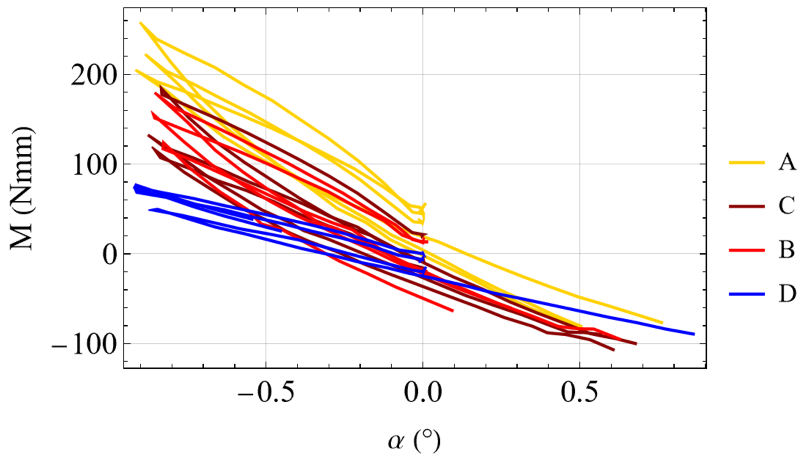


Figure 8: Measured bending response in the 2nd orientation of the sealing system.

To summarize the measured results, we approximated the linear part of the measured mechanical responses with a linear fit and calculated the average stiffness of the sealing system configurations for each of the load cases. The calculated linear stiffnesses are summarized in Table 2. Note that the stiffnesses are normalized by the length of the samples, therefore they represent a so-called line stiffness.

Table 2: Calculated mean line stiffnesses of the sealing system.

	Mean line stiffness		
ID	Tension (N/mm/mm)	Compression (N/mm/mm)	Bending (Nmm/°/mm)
A	20.8	30.4	4.0
B	28.9	22.6	3.6
C	18.8*	22.9	4.3
D	7.8	9.1	1.7

*…abnormal value, not used in further calculation

4. Modeling of the sealing system

To effectively model the sealing system in the numerical model, we designed a substitute sealing system shown in Fig. 9. The substitute model is effectively a single block of a homogenous material, with a determined thickness *t* and material elastic modulus *E*. The thickness and stiffness are calculated such that the substitute model mimics the measured line stiffnesses summarized in Table 2. The model's line stiffness in tension and compression is equal to the mean measured tension and compression line stiffness. At the same time, the model has a bending line stiffness equal to the measured one. The parameters of the substitute model are summarized in Table 3.

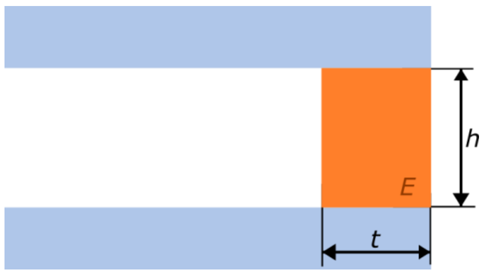


Figure 9: Substitute sealing system model.

Table 3: Substitute sealing system model parameters.

ID	Height *h* (mm)	Thickness *t* (mm)	Elastic modulus *E* (MPa)
A	12.1	10.4	29.8
B	18.4	9.8	48.4
C	18.4	11.3	37.2
D	18.4	11.7	13.3

5. Summary

We determined the effective stiffnesses of seal systems manufactured in 4 different configurations based on their measured mechanical response. Each configuration was loaded in tension, compression, and bending in two orientations. For each seal system configuration and load case combination, we measured and calculated the effective line stiffnesses summarized in Table 2. To apply these stiffnesses in the numerical model, we also designed a simple substitute model of the sealing system described in Chapter 4.