ACTUAL PROBLEMS OF STRUCTURAL SEALANT GLAZING

AKTUELLE FRAGESTELLUNGEN BEI GEKLEBTEN GLASFASSADEN

DES PROBLEMES ACTUELS SUR LES VITRAGES EXTERIEURS COLLES

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SUMMARY

Results of closed or running research projects of the FMPA on structural sealant glazing ar reported. The proceeding and the requirements of the German Building Inspection are quoted.

ZUSAMMENFASSUNG

Es wird über abgeschlossene und laufende Forschungsvorhaben der FMPA zum Thema der geklebten Glasfassaden berichtet sowie auf den aktuellen Stand der bauaufsichtlichen Behandlung eingegangen.

RESUME

Les résultats de projects de recherche en travailon terminés, effectués par la FMPA, sur le comportement de vitrages extérieurs callés sont rapportés et la situation actuelle du traitement par l'intendance des bâtiments est discutée.

1. PRELIMINARY REMARKS

The design with metal and glass is quite up-to-date worldwide as a look to modern architecture shows. The glass areas of roofs and façades become larger increasingly. Moreover glass is used not only as a member for closing the space but also as a strucural member for carrying over loads. The use of the material glass asks new questions to the engineer which up to now have not or not sufficiently been regulated in standards.

Glass products with different properties have to be considered:

- The load bearing behaviour of normal float glass can only be judged by means of the Weybull statistic. In case of damage this glass shows fragments with rather large areas.
- Toughened glass (ESG) has a significantly higher load bearing capacity by heath treatment. In case of damage a brittle crack pattern results.
- Heat strengthened glass (TVG) has a lower load bearing capacity than toughened glass but it almost shows the same crack pattern as float glass required for several applications.
- For laminated glass (VSG) two ore more glass plates are glued together by a suitable foil. In case of damage a residual load bearing capacity remains.

The use of the different glass products brings up questions:

- regarding the load bearing capacity and the safety factors,
- regarding the fastening technique,
- regarding the durability,
- regarding the consequences for the public safety and order in case of the destruction of a glass plate,
- regarding the safety in case of fire,
- regarding the protection against noise, humidity, heath and cold.

The subject of this essay aims to the fastening technique. Beside the usual continuous linear support at the edges of glass plates by a suitable clamp device, today fastenings at single points are used as well as continuous linear glue joints. Moreover for glass fins which support glass plates even friction or shear connections are used.

Glass as a brittle material does not offer the possibility of plastic deformations as steel. Therefore the fastening with an elastic glue joint of sufficient dimension is a material oriented procedure.

Such glueing for glass façades is known as Structural Sealant Glazing (SSG). In the following it is reported about questions, regulations and actual research programs in the field of SSG.

2. THE PROCEEDING OF THE GERMAN BUILDING INSPECTION

In Germany an approval of the building inspection is required for SSG systems. Corresponding applications are considered in the expert committee "Glas im Bauwesen" of the Deutsches Institut für Bautechnik. In table 1 companies are listed which already have an approval.

For all listed approvals the two components silicone DC 993 of the company Dow Corning is provided as the glue, in some approvals the two components silicones ELASTOSIL SG 460 and ELASTOSIL SG 500 of the company Wacker Chemie additionally.

All glue joints must be applied only in the factory, not on building sites. For each factory a production self-control and a regular third party inspection have to be provided. As usual the third party inspection includes a first general inspection of the factory (German procedure ÜZ).

In 1991 the Commission of the EU granted on request of the European Organisation for Technical Approvals EOTA a mandate for elaborating an approval guideline for SSG-systems. The discussions about the first part of this guideline (EOTA Guideline SSGS) for mechanically supported systems have been finished largely [1]. The second part for systems which are not mechanically supported is in preparation. The German experts take part at the meetings although Germany rejects this application.

The German approval procedure follows already the in clause 4 listed test programme of the draft of the EOTA guideline part 1.

3. MAIN STRUCTURAL REQUIREMENTS IN GERMANY

(1) The glue joints may be subjected by temporary actions (wind, temperature) only. For insulating glass units the change of the inner air pressure between the glass plates due to the change of the atmospheric air pressure and the temperature in comparison to the conditions of manufacturing shall be taken into account.The self-weight of the glass plates shall be transfered by mechanical device.

(2) In addition to the glue joints mechanical fastenings shall be provided which are able to carry over the maximum wind loads with single safety in case of need (braces additionally to the belt). This requirement shall prevent glass plates from falling down completely in the case of the failure of the glue joints

- due to fire,
- due to not sufficient durability.

Up to a hight of 8 m above the ground no mechanical fastemings are required.

(3) The glue joint shall have a thickness of 6 mm at least to achieve a sufficient flexibility.
(4) By suitable structural means it shall be avoided that movements of the building induce stresses into the glue joints.

(5) By suitable structural means it shall be avoided the collecting of water on the glue joints and its affecting there for a longer time.

(6) The deflection of the metal profiles supporting the edges of the glass plate may not exceed 1/300 of the corresponding length of the plate or 8 mm in case of insulating units. The deflection of the glass plate may not exceed 1/100 of its smaller span.

Table 1. *List of technical approvals for SSG-systems*

Company	Number	Name of the System
EKONAL	Z-36.3-21	Einsatzelemente der Glasfassaden EKONAL FV 70 SG
Josef Gartner	Z-70.1-2	Einsatzelemente für Rahmenlose Glasfassaden
Eduard Hueck	Z-36.3-8	Einsatzelemente der Glasfassade Hueck GF 60
Schüco International	Z-36.3-7	Einsatzelemente für Glasfassaden und -dächer FW 50 SG
	Z-36.3-17	Einsatzelemente für Schüco-Glasfassade System SG 50 N
Wehr	Z-36.3-11	Einsatzelemente für Glasfassaden Technivec WS 105 und WS 115
Fenster-Werner	Z-36.3-2	FW-Glas-Fassade
WICONA Bausysteme	Z-70.1-4	Einsatzelemente für Glasfassaden WICSKY 3
	Z-70.1-8	Ganzglasfassadenelement WICSKY 33.2-50

4. DURABILITY

In the course of the approval procedure 3 kinds of tests are required.

1) Tests for determining the identity of the glue (finger print):

- Specific mass,

- hardness,
- colour,
- thermogravimetric analysis,
- shrinkage,
- resistance to tearing,
- elastic recovery,
- gas inclusions.

2) Tests for determining the mechanical properties:
   - Stiffness and load bearing capacity under tension (-20°C, 23°C, 80°C),
   - Stiffness and load bearing capacity under shear (-20°C, 23°C, 80°C).
3) Tests for determining the durability under different conditioning:
   - Immersion in water at high temperature with and without solar radiation,
   - humidity and NaCl,
   - humidity and SO_2,
   - facade cleaning products,
   - micro-organism,
   - cyclic tensile loading tests,
   - effects of materials in contact.

The required tensile and shear tests in accordance with [1] are carried out with test pieces shown in figure 1.

The substrata themselves, the method of their cleaning and pretreatment as well as the glueing shall conform to the later use. Modifications of one link of the chain requires new tests and a supplement of the approval.

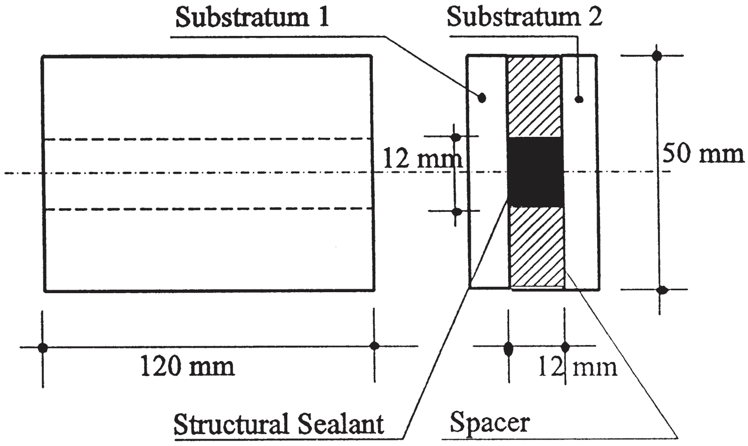

Fig. 1: *Test pieces for tensile and shear tests.*

For the up to now used two components silicones the immersion in water at high temperature turned out to be the most critical conditioning. On account of this experience the in clause 3.5 given regulation has been provided.

In the following some results are quoted from a research project of the FMPA [2] The tensile tests for this project were carried out with an opposite to figure 1 modified test piece. The width of the glue joint was 40 mm, it length 50 mm. This is of importance since the resulting tensile strength is no specific material quantity but depending on the geometry of the test piece.

The tests were carried out for two different two components silicones A and B. The listed results represent in each case an average of five samples.

As a requirement adhesion failure may not occur whereby the loss of adhesion needs a practicable interpretation. In [2] the loss of adhesion is defined as the quotient of the area parts without adhesion and the total area of the glue joint quoted in per cent. The partial areas on the substratum with loss of adhesion were estimated by inspection with transparent millimetre paper.

The tensile strengthes listed in table 2 resulted without conditioning. Adhesion failure did not occur, the loss of adhesion was less than 10%, respectively.

Table 2: *Tensile strength without conditioning*

Silicone	Age of the test pieces weeks	Tensile strength N/mm²
A	2 33	0,97 1,05
B	1 4 9 48	0,62 0,61 0,61 0,76

After immersion in water at temperatures of 40°C, 60°C, and 80°C the tensile strengthes of table 3 resulted depending on the aging. The tensile strengthes of the silicone A are plotted as a graphic diagram in figure 2 additionally.

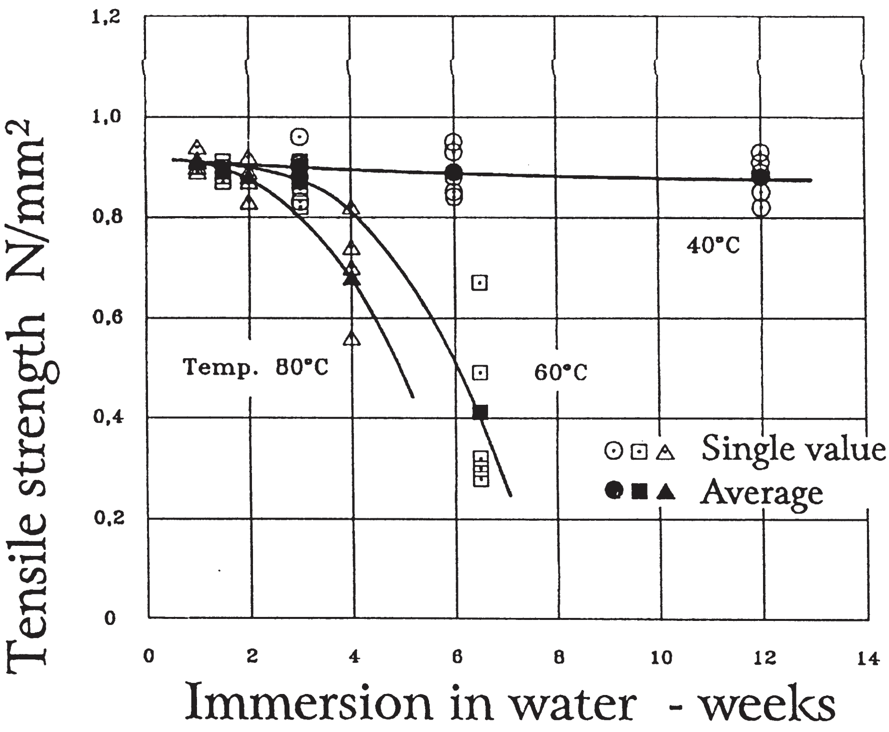

Fig. 2: *Tensile strength of the Silicone A after immersion in water.*

Table 3: *Influence of immersion in water and temperature on tensile strength and loss of adhesion.*

Silicone	Temperature of water °C	Time of immersion weeks	Tensile strength N/mm²	Loss of adhesion %
A	40	3	0,90	1,0
		6	0,89	2,3
		12	0,88	6,9
	60	1,5	0,89	4,6
		3	0,87	22,5
		6,5	0,41	100
	80	1	0,91	6,4
		2	0,88	16,0
		4	0,68	54,3
B	40	3	0,53	0
		6	0,56	0
		12	0,51	0
	60	1,5	0,42	0
		3	0,44	11,7
		6,5	0,24	60,6
	80	1	0,43	4,5
		2	0,44	11,0
		4	0,33	32,2

The results show clearly the decrease of the tensile strength for increasing temperature and for increasing period of immersion. Along with the loss of adhesion increases. The silicone B which has a lower tensile strength from the beginning turned out to be less sensitive against conditioning.

The silicone glues are reported to recover when they are dried again after immersion in water. Therefore in [2] the behaviour of the silicones was tested resulting from cyclic conditioning water immersion/drying.

Table 4 shows the results after cyclic conditioning

- 3 x 6 weeks water immersion at 600 C and
- 3 x 4 weeks drying at the air by 200C / 50% humidity.

Table 5 shows the results after cyclic conditioning

- 3 x 4 weeks water immersion at 800 C and
- 3 x 4 weeks drying at the air by 200C / 50% humidity.

Table 4: *The influence of cyclic conditioning with immersion in water and temperature of 60° C.*

Silicone	Tensile strength N/mm²	Loss of adhesion %
A	0,66	88,4
B	0,53	36,9

Table 5: *The influence of cyclic conditioning with immersion in water and temperature of 80° C.*

Silicone	Additional exposing to air weeks	Tensile strength N/mm²	Loss of adhesion %
A	0	0,34	100
	3	0,35	100
	6	0,40	99,4
B	0	0,20	95
	3	0,28	94
	6	0,30	85,8

The parameters chosen for the cyclic conditioning are rather extreme and do not occur in reality. Nevertheless the results show no complete recovery when periods of drying follow periods of water immersion, but an increase of the loss of adhesion. In the course of years an slowly increasing damage of the glue joints - though surely less - can not be excluded. The more the requirement should be fulfilled to avoid the gathering of water on the glue joints.

5 THE VERIFICATION OF THE LOAD BEARING CAPACITY.

The in table 1 listed approvals limit the tensile stress normal to the glue joints to 0,12 N/mm². Furthermore the shear elongation due to a difference of temperature of ΔT = 35 K shall be less than 12,5%. The superposition of tensile and shear stresses is not required.

The tensile stresses in the glue joints are calculated by a simple approach. The wind load is distributed uniformly to the longer sides of a glass plate using the following formula (figure 3).

$$\sigma_{si} = \frac{q \times b_{gl}}{2{,}0 \times b_{si}} \leq 0{,}12 N / mm^2$$

whereas are

b_{gl} shorter side of a glass plate

b_{si} width (bite) of the glue joint

q wind load

σ_{si} tensile stress in the glue joint

The resulting width of the glue joint b_{si} is valid for the whole circuit.

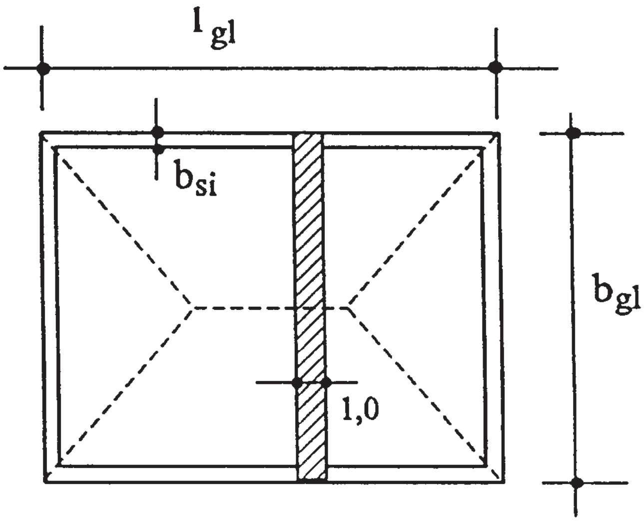

Fig. 3: *Distribution of wind loads.*

This rough approach does not take into account:

- the from the plate effects resulting non-linear distribution of the stresses along the edges even with a change of the sign around the corners,
- the width and the thickness of the glue joint and the from it resulting restraining bending moments along the edges,
- the influence of other components as the stiffness of the supporting frame and the blocker,
- the dimensions of the glass plate and its bending stiffness,
- the specific material properties of the silicone.

Already the publications [3] and [4] show more complex stressing of the glue joint as a simple tensile stress (figure 4).

In a further research project [5] the FMPA traced the influence of the mentioned parameters using finite element calculations whereby the glue joint was modelled with finite elements also. A challenge was the inclusion of the material properties of the glue. The silicone shows the typical properties of rubber like elastomeres: A low modulus of elasticity, almost incompressibility and a significant non-linear stress-strain-characteristic in connection with large elastic deformations.

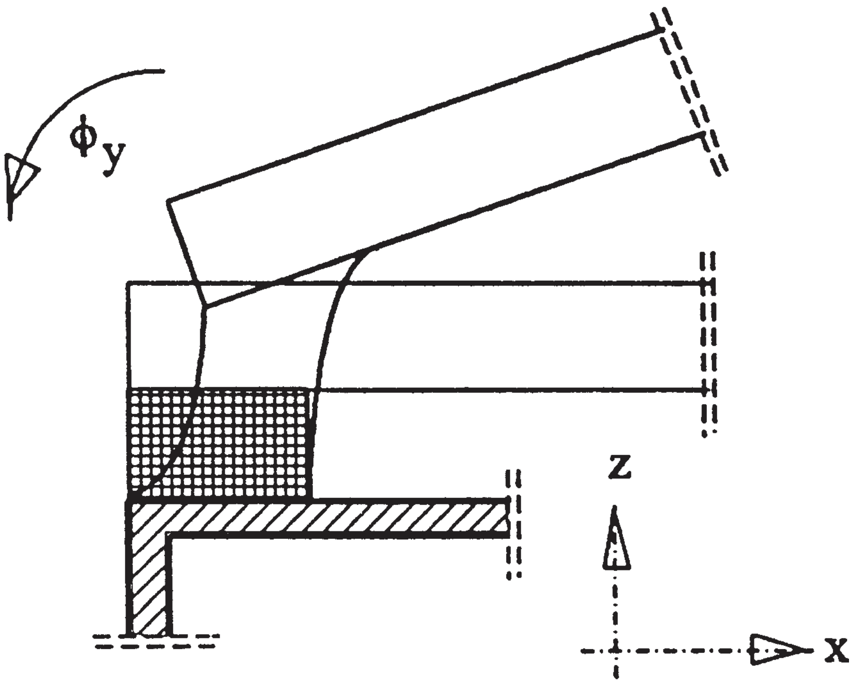

Fig. 4: *Possible deformations of the silicone.*

For the modelling of these material behaviour within the FEM software ANSYS 3D-solid elements with a hyperelastic capability (Mooney-Rivlin option) were used. The Mooney-Rivlin material parameters were determined by re-calculation of detail tests (figure 1).

The deformation behaviour of the glue joint can be modelled quite well as the comparison with results of component tests shows. As an example figure 5 shows the out-of-plane displacements u_z of the glue joint along its edges of the glass plate drawn from the corner until the middle of the sides for two different wind suction loads. In each case two different curves are plotted, one for linear and the other for non-linear material behaviour. The differences between both become larger for the higher wind load, but alltogether they remain small.

The difference between the stresses for linear and for non-linear behaviour can become almost the factor 3. But this statement does not help farther first. Up to now no suitable failure criterion exists for silicones. The in clause 4 given tensile strengthes are no specific material characteristics but depending on the geometry of the test piece and its special stress distribution.

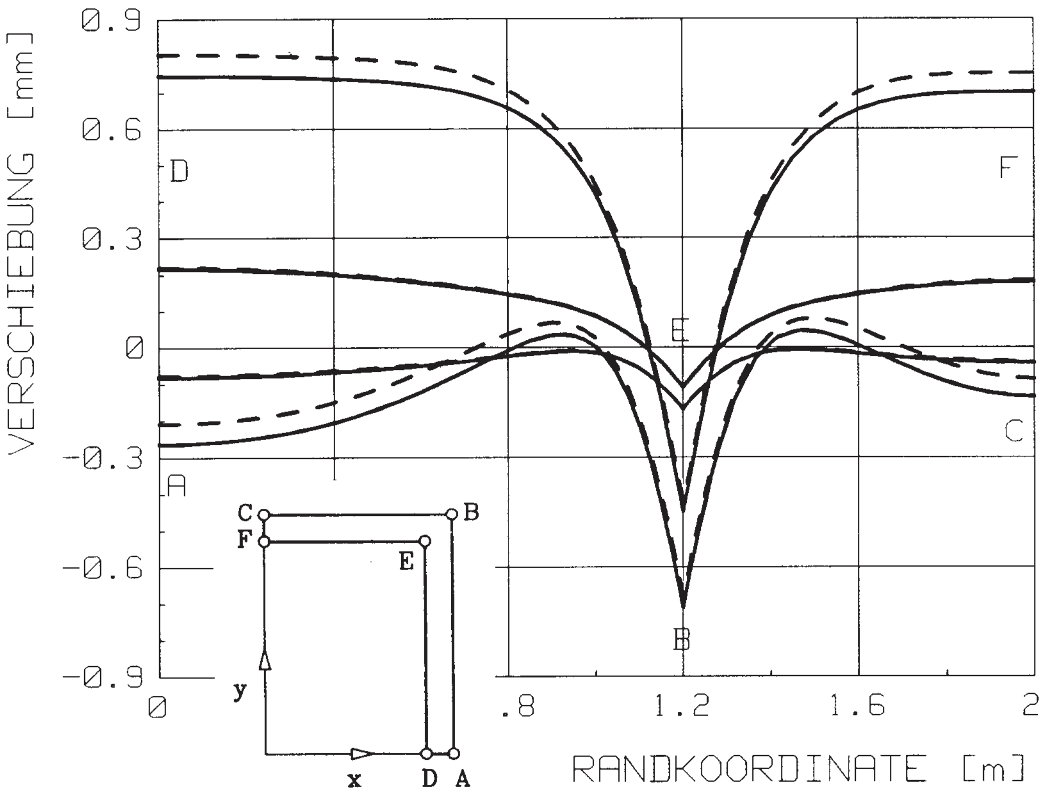

Fig. 5: *Displacements u_z along the edges of the glue joint.*

At present the FMPA works at a new research project to develop the missing failure criterion. Up to now the expert committees had the opinion to cover all influences on the safe side by a rather high safety factor. Refering to the tensile strengthes without conditioning quoted in table 2, for wich an uniform permissible stress of 0,12 N/mm² is fixed, the global safety factor amounts to about 7 and 5. This seems not to be very much considering the neglected parameters and the results in [5] as well as the influences from manufacturing and climatic claims.

6 INSPECTION OF FACADES

Architects are strongly interested to carry out structural glazing without additional mechanical fastenings. If the problem of fire resistance could be solved, the question of the durability would remain. It is discussed, to have regular inspections of the facades instead of mechanical fastenings. Recently, in publications from the United States [6], [7] short inspection intervals are suggested, i.e. in [7] inspections after 6 months, 1 year and 2 years after completion of the facade and in the following depending on negative results.

However, visual inspection does not provide objective and reproducable results and often it is made more difficult, since the structural sealant is not directly visuable. Within a further research project the FMPA is investigating, how far the vibration analysis after excitation by a short impact could be useful for detection of structural faults.

The requirements for practical use in field are a simple instrumentation and the results should be available immediately. To approach this task, not only single frequencies, but the whole information of the vibrational spectra was considered. A comparative analysis was performed by the calculation of cross spectra and an integral correlation factor $0 \leq I_c \leq 1$. This allows an easy good bad discrimination and fulfills the the requirements for practical use.

The SSG element represents a plate elastically supported along it's edges with the ability of transverse flexural vibration. The natural frequencies depend on the boundary conditions (joint stiffness and geometry). The associated mode shapes reflect the plate symmetry.

The reponse to a short impact normal to the plate is a damped vibration consisting of a superposition of the induced modes of vibration (fig.6). An extended defect in the structural sealant causes changes to the mode shapes and the modal parameters (frequency, damping rate, amplitude). The response spectrum in comparison to an intact SSG element shows an increased contribution to the amplitudes at low frequencies on the whole (fig. 6), while the frequency shifts are only a few percent. However, with increasing degree of damage modes of low symmetry localized at the defect ('defect modes') can be observed (fig.7).

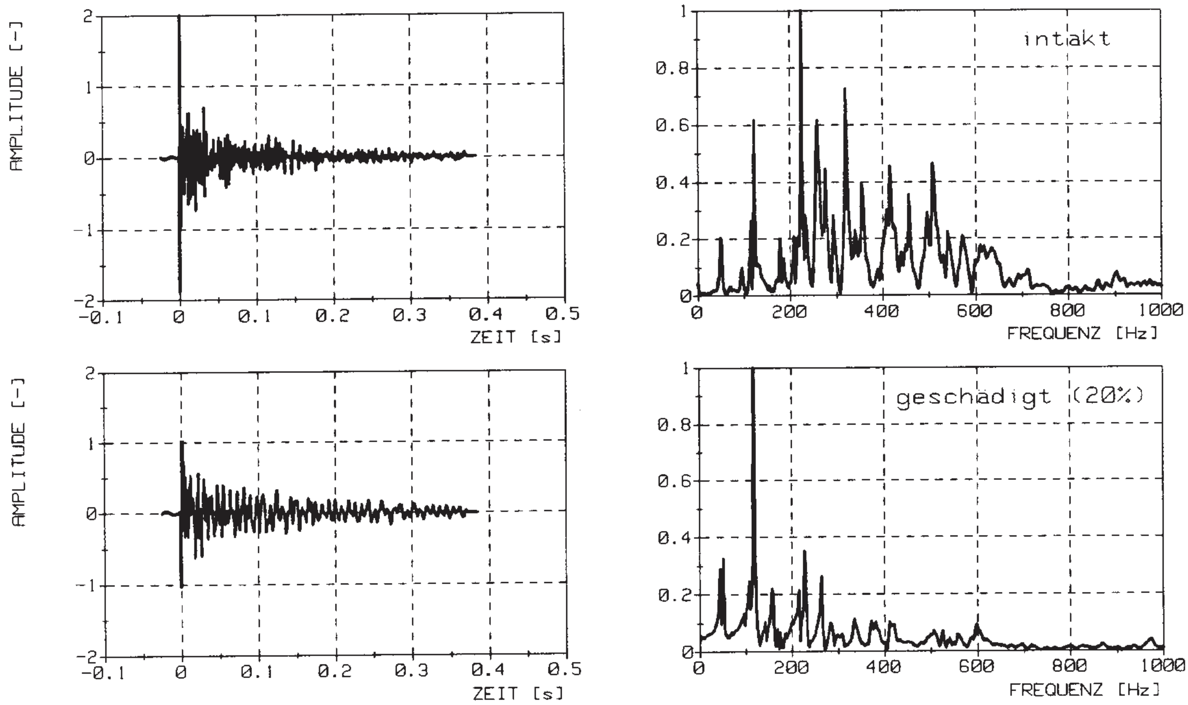

Fig. 6: *Measured time signals and spectra of an intact and of a damaged SSG-element (20 % grade of damage).*

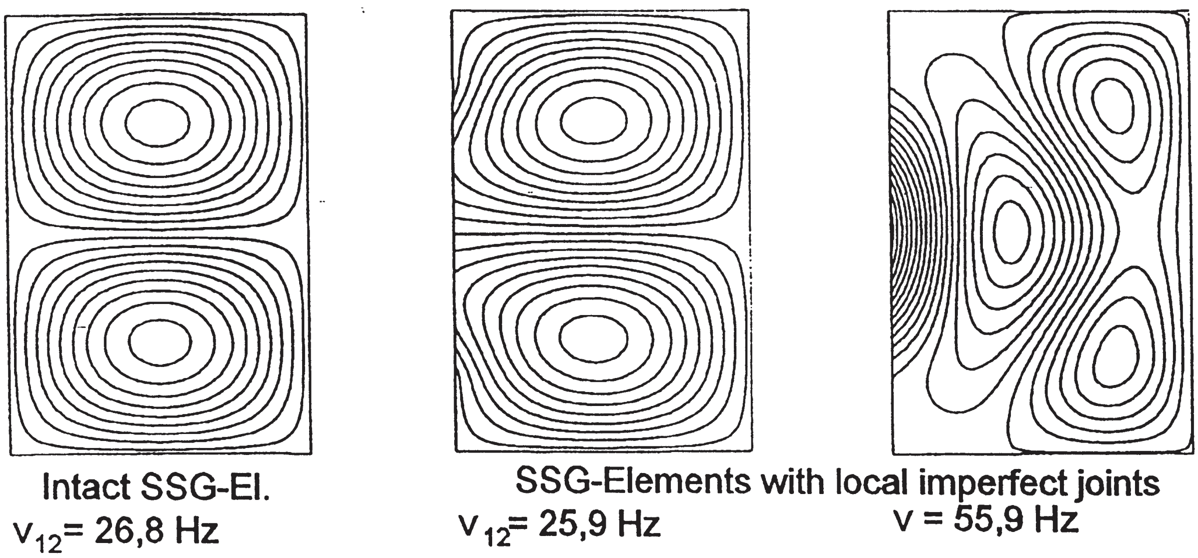

Fig. 7: *Calculated mode pattern of an intact SSG-element and elements with local defect joints. In the right detail a defect mode is located at the position of the imperfection.*

Tests on full scale SSG elements and FEM calculations showed a decrease of the correlation factor Ic below 0,9 for a degree of damage ß > 5%. This is significantly below the standard deviation oberserved in the test.

However, the application to SSG elements consisting of laminated safety glass is reduced, since the PVB foil (poly vinyl butyral) mainly used in practice shows a strong temperature dependence of it's mechanical properties (fig.8).

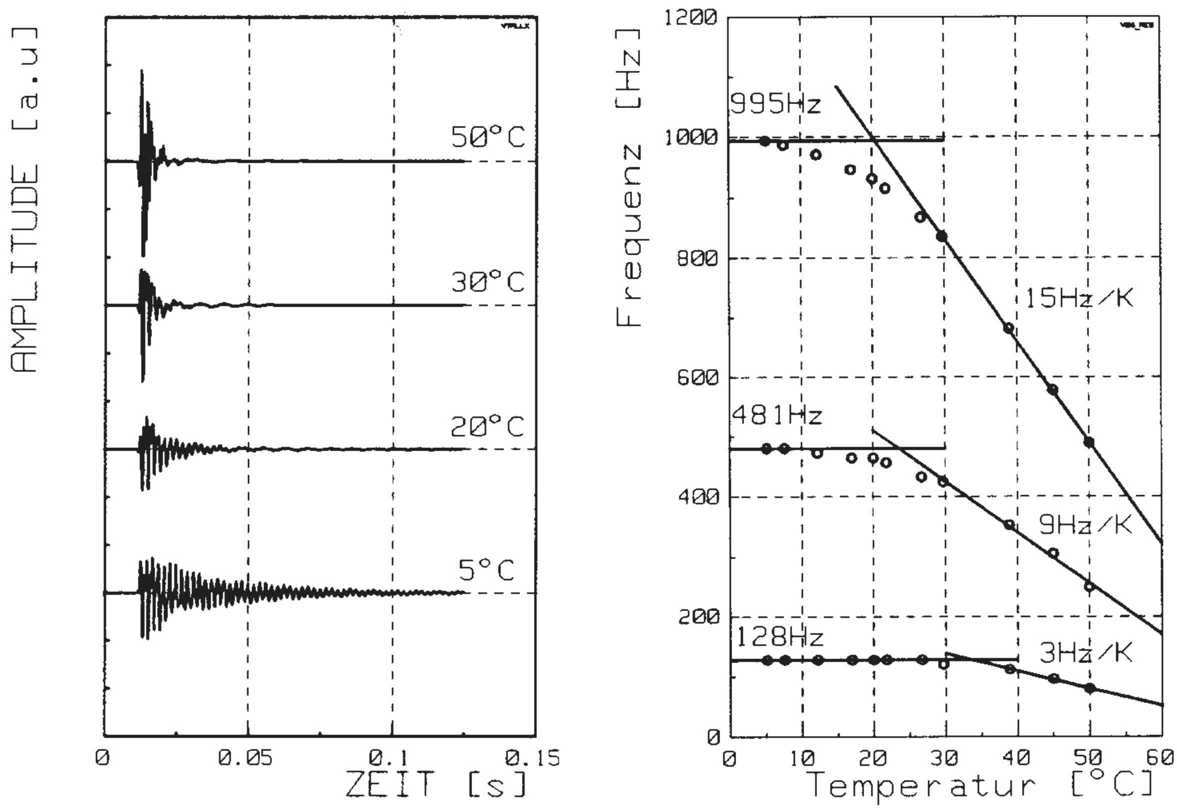

Fig. 8a: *Measured time signals at different temperatures of a beam of laminated glass excited to flexural vibration.*

Fig. 8b: *Dependence on temperature of the lower eigen frequencies.*

Frequently SSG is used with double glazing insulation units. The vibrational modes of the individual glass plates are coupled by the gasket and the confined gas volume. In the case of symmetric insulation units, the coupling breaks off the degeneration. For the modes with an even number of half waves coupling is small and doublets of lines can be found in the spectra (fig.9), corresponding to the modes with in phase and anti phase vibration of the single glass plates. Since anti phase vibration leads to a net volume change, the modes with an uneven number of half waves, in particular the fundamental mode, undergo to a more strong coupling by the confined gas volume.

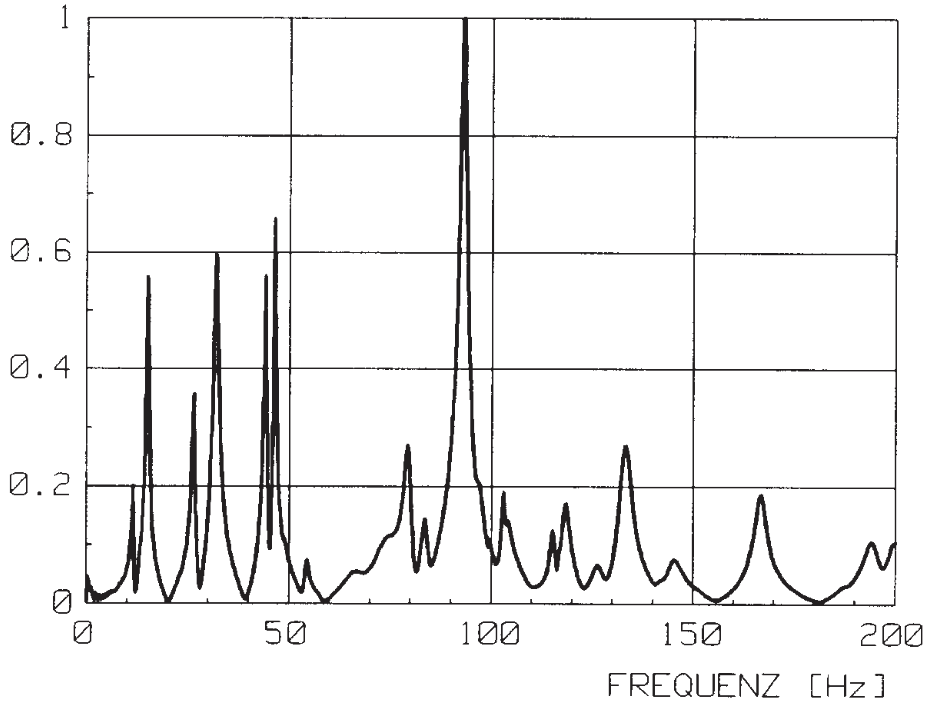

Fig. 9: *Typical vibration spectrum of an insulating glass unit.*

The anti phase vibrations of an insulating glass unit are only slightly sensitive to defects in the structural sealant. Hence, this almost constant part in the spectra shows a difficulty for detection of defects in comparison to the SSG element with a single glass plate.

LITERATURE

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