Novel Tempered Flat Glass and its Potential

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Abstract

The minimum thickness of flat glass to be thermally pre-stressed is generally considered to be approx. 2 mm. Lower thicknesses can also be realised by using tempering furnaces without the classic roller transport, but only to a minimum thickness of approx. 1.5 mm. Achieving thermally toughened glass (TTG) quality (criteria fine fracture pattern) becomes more and more difficult as the thickness is reduced. However, a pre-stressing process of lower glass thicknesses can be realised with the chemical pre-stressing process. The disadvantage of this process is that it is very time-consuming (8 to 48 h) and therefore also cost-intensive. Another disadvantage especially with soda lime glass is the low pre-stressing depth of 10...50 µm. Microdefects caused by the manufacturing processes involved in flat glass processing (cutting, lamination, ...) are often deeper, which means that the full potential of chemically pre-stressed glass with high pre-stressing values cannot be exploited in practical construction terms. A novel pre-stressing method provides rapid chemical strengthening of flat glass. The process time is around 30 minutes. This novel process compensates the lower pre-stressing depth of chemical tempering with similar strength values. This method can also be used to pre-stress thin glass up to 0.5 mm and the geometrically undesirable changes in geometry (e.g. roller waves) are significantly less in comparison to thermally pre-stressed glass. The paper presents the results of a study on small samples (100 x 100 x 4 mm³). The following aspects are examined in the investigations: Fracture pattern analysis; strength (coaxial double ring test), anisotropy and pre-stress values of the glazing. For the comparison, the following series of identical base glass are compared with each other.

Keywords

pre-stressing glass; novel strengthening method, annealed glass, chemically tempered glass

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1. Introduction

For decades, flat glass and curved glass has been successfully thermally pre-stressed or toughened, among other things to meet safety requirements (thermally toughened soda lime silicate safety glass) and to realise lower glass thicknesses. During the process, compression stresses are generated near the surface, which compress existing cracks on the glass surface and thus significantly increase the glass strength. This process takes less than 10 minutes and is economically efficient for the architecture and automotive sector. There are two products of thermal pre-stressed glass. These are heat strengthened glass (HSG) according to EN 1863-1 (2011) and thermally toughened glass (TTG) according to EN 12150-1 (2020). In contrast, chemical pre-stressing (diffusion process of alkali ions) takes up to 48 hours and the glass is only pre-stressed very close to the surface under high compressive stresses up to 600 MPa Schneider et al. (2016). The depth of the compressive stress zone for soda lime silicate glass typically remains under 50 µm (Sane and Cooper, 1987). Due to the limited penetration depth and the presence of surface flaws, the effective or practical strength of chemically strengthened soda lime glass is approximately 150 MPa (characteristic strength value as specified in EN 12337-1 (2000)). Chemically tempered glass is mainly used for displays and yacht glazing. It offers advantages such as the absence of distortions (e. g. roller waves) and optical anisotropy effects, commonly observed in thermally tempered glass. However, the chemical strengthening also has disadvantages: higher production costs, sharp-edged fragments and increased susceptibility to surface corrosion if improper cleaning procedures are applied.

Combining both pre-stress methods could synergistically utilize their respective advantages and potentially mitigate their disadvantages. This approach was explored by Voland (2015) on glass bowls and Zaccaria (2016) on flat glass, produced by sequentially applying thermal followed by chemical tempering. The chemical step in this process ranges in Zaccaria (2016) from 1 to 6 hours in duration. Unfortunately, no commercial application of this method is known for flat glass.

A novel strengthening process for glass structures was developed by the company Revisalt (start-up of TU Bergakademie Freiberg). This approach combines thermal and chemical pre-stressing not sequentially but simultaneously. This process is characterised especially by significantly reduced process times of up to a minimum of below 0.5 h and the parallel tempering process. In the new tempering process, the heated glasses are brought into contact with molten salt (potassium nitrate salt). This approach theoretically enables the tempering of complex glass geometries, including hollow glasses and multi-axially curved flat glass.

This contribution is driven by the idea to establish a new pre-stressing method for flat glass and to evaluate their potential. A first, methods for the pre-stressing of glass will be introduced. This is followed by a description of the examination methods for the glasses. The investigations results (anisotropy, pre-stress levels, strength and fracture pattern) will be presented. Finally, the findings are critically discussed regarding their practical feasibility and potential in real architectural glass structures.

2. Methods

2.1. Pre-stressing methods

The aim of tempering the glass is to create a state of residual stress in the glass that causes compressive stresses on both surfaces in order to increase the strength of the glass structure by compressing surface defects. For reasons of equilibrium, tensile stresses occur in the core of the glass. In principle, there are 2 different methods (thermal and chemical pre-stressing process) and hybrid approaches. The various methods will be explained briefly in this section.

Thermal pre-stressing

Thermal pre-stressing is an important process for strengthening of automotive and architectural glass (Lauf (2000)). During thermal pre-stressing, the flat glass is heated uniformly to approx. 630°C and then cooled rapidly using compressed air. This creates a parabolic residual stress profile in mechanical equilibrium through the thickness of the glass, resulting in surface compressive stresses and tensile stresses in the core of the glass pane (see Figure 1; here TTG - Thermally toughened glass). The compression zone is 20% of the glass thickness on each surface. With this process, the glass can be pre-stressed very quickly within a few minutes. However, the achievable compressive stress is limited and is no longer sufficient for thin glass below 1.5 mm (approx.) In addition, the achievable quality (e.g. haze, roller waves, anistropy effects)is rather low due to the high process temperatures. Further information on thermal pre-stressing can be found in Barr (2012), Laufs (2000) and Schneider et al. (2016).

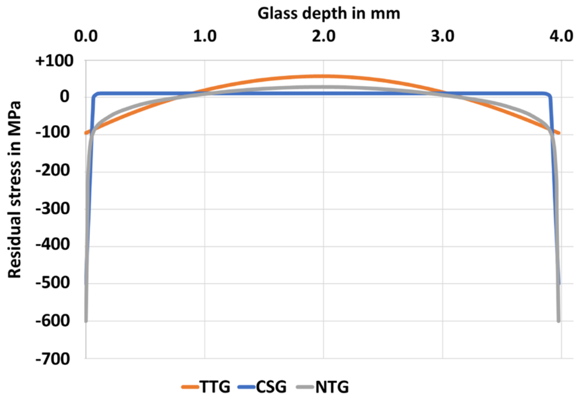


Fig. 1: Stress profiles (schematic image) of thermally toughened glass (TTG), chemically strengthened glass (CSG) and novel toughened glass (NTG) for 4 mm thick flat glass.

Chemical pre-stressing

In chemical strengthening process, the glass is immersed in a molten alkali nitrate - usually potassium nitrate - below the transformation temperature, usually in the temperature range between 400 and 480°C (Voland (2021)). This results in an ion exchange between the alkali ions present in the glass - usually sodium - and the larger alkali metal ions present in the molten salt, usually potassium. Due to the low relaxation process at process temperature and the larger ionic radius of the potassium, high compressive stresses build up on the surface up to 600 MPa for soda lime silicate (Schneider et al. (2016)). The stress-profile of the resulting product chemically strengthened glass (CSG) is illustrated in Figure 1. The surface quality of the glass is excellent due to the low process temperatures. The disadvantages are the long process times for ion exchange (up to 48 h), the low achievable penetration depth and the sometimes higher susceptibility of the glass to corrosion (see Gösterişlioğlu (2020)). For further details regarding chemical strengthening or pre-stressing see Karlsson, Jonson and Stålhandske (2010) or Musgraves, Hu and Calvez (2019).

Thermal and chemical pre-stressing (hybrid approach, sequential)

There are also processes that combine both approaches. A hybrid approach (sequential) was used to pre-stress washbasins at the TU Bergakademie Freiberg by a thermal and then a chemical process. Enormous glass strength of the glass can be achieved (see Häußler (2014), Voland, Börner and Kretschmar (2015)). The disadvantage is the very high process costs. A similar process is described in Zaccaria (2016) (named “bi-tempered glass”) for flat glass. Here, flat glass panes were thermally tempered and then subjected to ion exchange. This process achieves comparable results. Further details regarding the process of bi-tempered glass are listed in Zaccaria (2016).

Thermal and chemical pre-stressing (hybrid approach, parallel)

The hybrid sequential approach for a novel pre-stressing method was developed by the company Revisalt. In the process, at first the glass is pre-heated in a furnace to a temperature that is usual for thermal toughening (see Figure 2 a)). The hot glass is then immersed in a potassium nitrate melt, which is at the usual temperature for chemical tempering. This results in the formation of thermal stresses in the glass due to the rapid cooling. The glass remains in the molten salt for a short period of around 30 minutes, where ion exchange takes place (see Figure 2 b)). This is considerably accelerated by the process conditions. At the end of the process, the glass is removed from the salt and processed in a similar way to the CSG samples. The schematic illustration of the resulting pre-stressing profile of this hybrid approach is shown in Figure 1. The residual stress values resulting out of the chemical part should be within the range of those produced by purely chemical pre-stressing approach for CSG. Exact preheating temperatures and other process parameters cannot be disclosed for reasons of confidentiality.

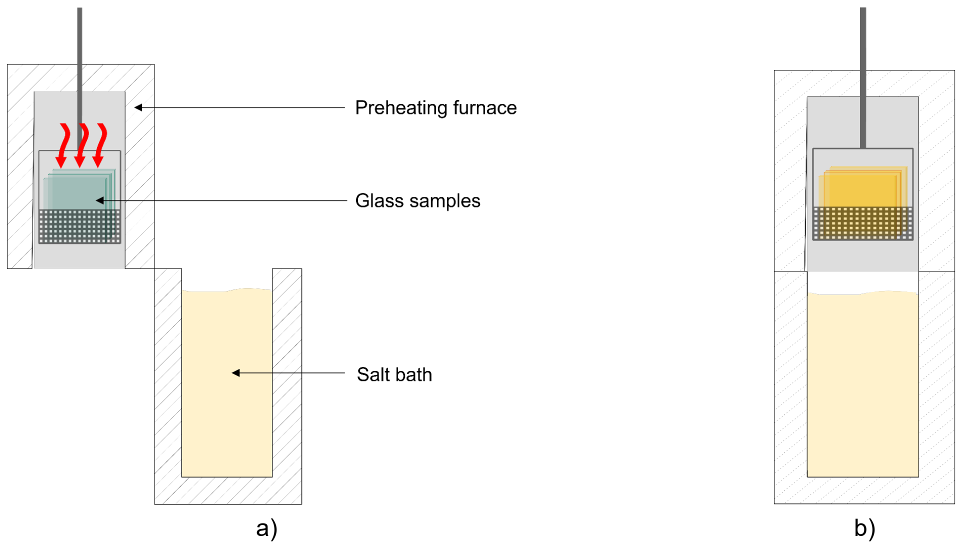


Fig. 2: Image of novel pre-stressing method for novel toughened glass (NTG): a) Heating phase (1st step); b) Immersion in salt bath (2nd step).

2.2. Evaluation of the residual stress and anisotropy

The non-destructive measurement of surface pre-stressing of three samples per series was carried out with the measurement device SCALP-05 (Scalp (2025)). The measurements were recorded in the middle of each sample in one direction and at one surface. Three individual measurements were taken. The setting parameters for the software were: C 2.72 1/TPa; local fitting (series A, B, C, E) close fitting 1; 3rd order polynomial, fixed retardation on and background normal. For the measurement of Series D the fit method chemical was chosen. Additional anisotropy scans with the line scanner (company Softsolution) were conducted. Anisotropy images are used to detect uneven pre-stress distributions or process errors during the manufacturing.

2.3. Distribution of fracture pattern

Three sample of series B to E were broken with a centre punch in combination with a steel hammer in the corner area. The glass specimens were supported continuously on a rigid plywood panel. The impact location was approx. 20 mm away from both edges (see Figure 4). The analysis of the fracture patterns should help to identify irregularities in the pre-stressing distribution and process.

2.4. Coaxial double ring test

The double ring bending test were conducted using a setup adapted from the principles outlined of EN 1288-5 (2000) to determine to bending strength of the different series without the influence of the glass edge. For this test, a universal testing machine (ZWICK ROELL Z050) was used. The load was gradually increased under force control until fracture occurred. A stress rate of 2 ± 0.4 MPa/s was maintained throughout the test. The diameters of the loading and support rings were 11 and 30 mm, respectively. The calculation of the failure stresses were conducted via equation (1) in EN 1288-1 (2000) with a Poisson's ratio of 0.23.

2.5. Test samples

The test samples for the evaluation of the novel toughened glass type (NTG) in comparison to other series without processing and with other pre-stressing processes were made of the same basis glass batch. All tests are conducted with flat glass out of soda lime silicate glass (SLG) in accordance with EN 572-2 (2012). The plan dimensions of all samples were 100 mm x 100 mm with a nominal thickness of 4 mm. The measured thickness values were between 3.82 and 3.85 mm. The usual geometries (plan dimensions 1100 x 360 mm²) in accordance with the product standards EN 12150-1 (2020), EN 1863-1 (2011) and EN 12337-1 (2000) were not used for the fracture pattern and strength tests. The reason was that the production of these formats was not yet feasible for the new toughened glass type. The edge processing type was smooth ground edge. An overview of all series with the corresponding pre-stressing process and the investigations methods are illustrated in Table 1. For comparison purposes, a series without pre-stressing process was tested as well (series A). The pre-stressing processes were conducted with the "standard" process parameters by the manufactures for the corresponding glass type in Table 1. The CSG samples (Series D) were preheated to 440°C for 10 minutes and then exposed to a 440°C potassium nitrate melt for 16 hours. After removal, the samples were first transferred to an oven at 150°C and removed after 5 minutes dwell time. They were cooled freely to room temperature and then washed with tap water and deionised water. The processing of the novel toughened glass (NTG) is described in section 2.1.

Table 1: Overview of the test series and amount of samples per investigation method.

Glass type / product	Pre-stressing type	Standard	Series	Amount of samples in total	Investigation method			
					Anisotropy scanning	Residual stress measurement	Fracture pattern distribution	Strength (Coaxial double ring test)
Annealed soda-lime silicate glass (ANG)	-	EN 572-2 (2012)	A	16	Yes (all)	No	No	Yes (10)
Heat strengthened glass (HSG)	Thermal pre-stressing	EN 1863-1 (2011)	B	15	Yes (all)	Yes (3)	Yes (3)	Yes (10)
Thermally toughened glass (TTG)	Thermal pre-stressing	EN 12150-1 (2020)	C	15	Yes (all)	Yes (3)	Yes (3)	Yes (10)
Chemically strengthened soda lime silicate glass (CSG)	Chemical pre-stressing	EN 12337-1 (2000)	D	15	Yes (all)	Yes (3)	Yes (3)	Yes (10)
Novel toughened glass (NTG)	Thermal+ chemical pre-stressing	-	E	13	Yes (all)	Yes (3)	Yes (3)	Yes (10)

3. Results of experimental investigation

3.1. General

In this chapter, the results of the experimental investigations are presented in order to evaluate the new pre-stressing method in contrast to the other methods.

3.2. Residual stress distribution and anisotropy

Table 2 shows the results of the residual stress measurements of three samples per series. Based on the measured values of three samples, mean value and standard deviation were determined of each series. Exemplary residual stress profiles over the glass thickness for each series without series A are illustrated in Figure 3. The stress profiles for series B, C and E are typical for thermal pre-stress glass and for series D it is typical for chemically strengthened glass (see Musgraves, Hu and Calvez (2019)). The value for series A (annealed glass) has a “low” level of residual stress for the annealed state. The value for heat strengthened glass are too high in comparison to the values in Pisano et al. (2022). In contrast, the measurement values for series C are in line with the typical values of thermally toughened glass in Pisano et al. (2022). The chemically strengthened glasses (series D) exhibit a high degree of measurement variability. This is consistent with the known difficulty of conducting reliable pre-stress measurements using the SCALP device, which is prone to substantial measurement scatter for chemically strengthened glasses. The mean value of the pre-stress value for series E (BTG) is -32 MPa by a standard deviation of 0.3 MPa. The stress profile for the E series samples (see Figure 3) is typical of a thermally toughened glass. Even with other settings of the scalping device it was not possible to measure the chemical pre-stress part of series E. However, the retardation plots indicate that series E glass exhibits a significant difference (hook shape at approx. 50 µm below the glass surface) compared to the purely thermally toughened glass near the surface (see Figure 3 retardation plots). This pre-stress level is below the typical level for HSG (see Pisano et al. (2022)).

Table 2: Investigation of the residual stress: Results out of “SCALP”-measurements.

Glass type / product	Series	Sample	Results		
			Mean value	Standard deviation	Mean value (standard deviation) per series
Annealed soda-lime silicate glass (ANG)	A	A-14 A-15 A-16	-2.6 -2.9 -2.9	0.1 0.1 0.1	-2.8 (0)
Heat strengthened glass (HSG)	B	B-13 B-14 B-15	-92.6 -94.7 -89.6	0.7 0.6 1.3	-92 (0.4)
Thermally toughened glass (TTG)	C	C-13 C-14 C-15	-110 -106.9 -107.4	0.7 0.4 0.7	-108 (0.2)
Chemically strengthened soda-lime silicate glass (CSG)	D	D-13 D-14 D-15	-150.2 -268.8 -171.8	59.7 53.1 9.3	-197 (27.4)
Novel toughened glass (NTG)	E	E-12 E-13 E-14	-32.7 -32.8 -31.2	0.2 0.7 0.1	-32 (0.3)

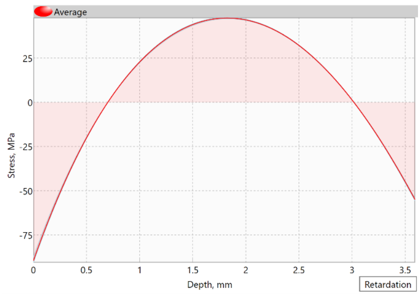
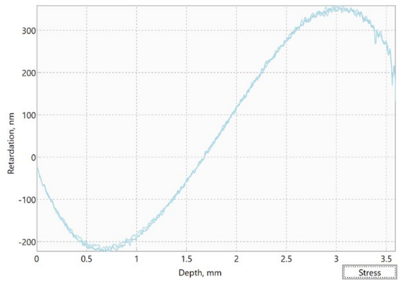
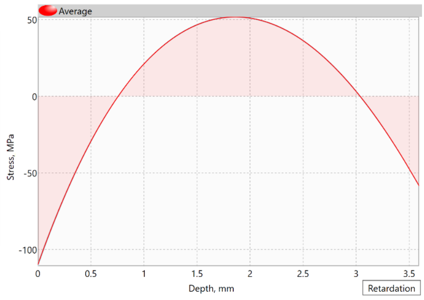
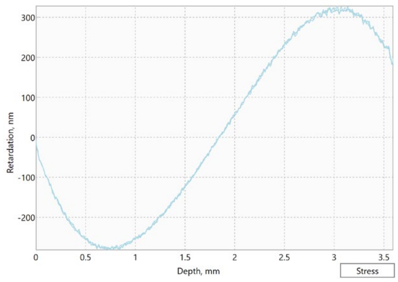
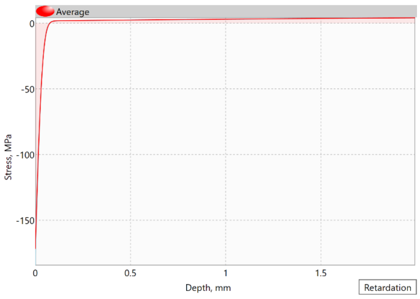
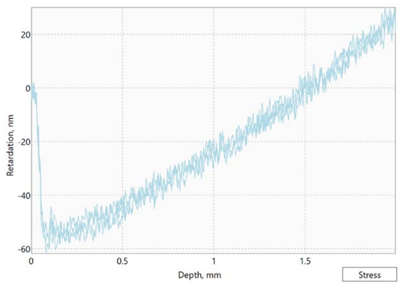
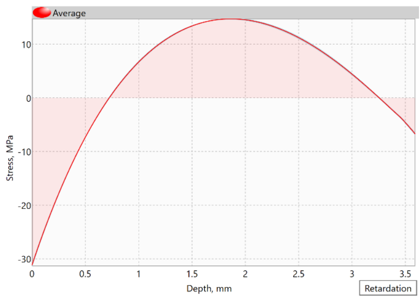
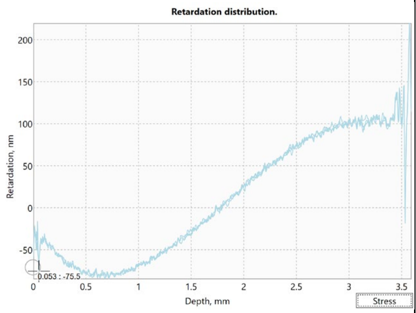
Series (Sample)	Glass type/ product	Stress profile over the thickness (mean value)	Retardation profile over the thickness (three curves)	Comments
B (B-14)	HSG			Measurement depth 3.6 mm
C (C-13)	TTG			Measurement depth 3.6 mm
D (D-15)	CSG			Measurement depth 2 mm
E (E-14)	NTG			Measurement depth 3.6 mm

Fig. 3: Distribution of the residual stress (pre-stress) and retardation over the glass thickness of one sample of series B to E.

Figure 4 shows anisotropy images and the fracture pattern distribution, exemplary for each series. Non-uniformly pre-stressed samples are clearly visible by the change from light to dark in the surface area. Due to the directional stress changes in the edge and corner areas of thermally prestressed panes, this effect is much more noticeable in these areas. The annealed glass (series A) and the chemically strengthened glass (series D) show no anisotropy effects. In the case of the thermally pre-stressed series B and C, stress differences are clearly recognisable, especially for series B. The surface of the E series shows no noticeable stress variations. The typical transition from light to dark, characteristic of thermally pre-stressed flat glass, is only observed in the corner regions. Due to the immersion process for series D and E, there should be minimal or no stress differences in the surface area of series D and E.

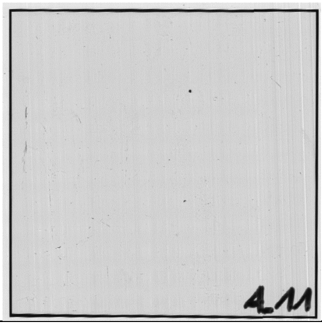
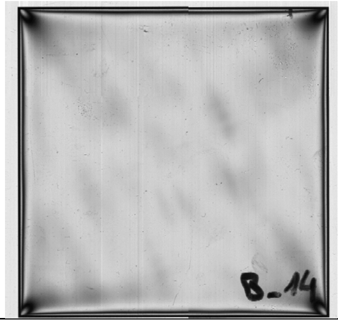
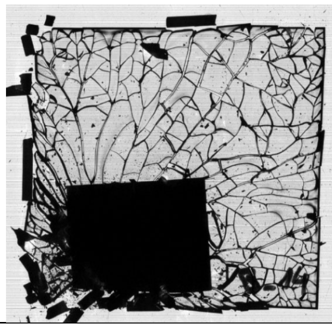
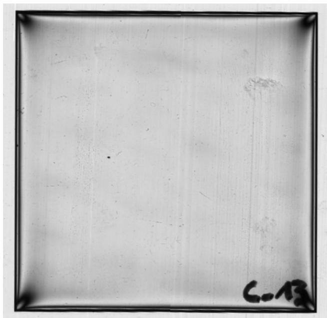
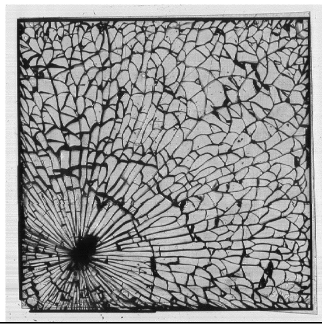
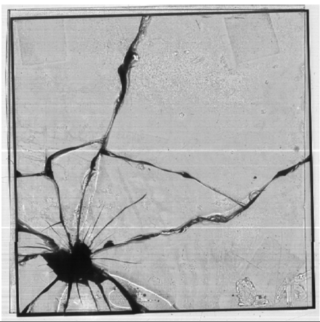
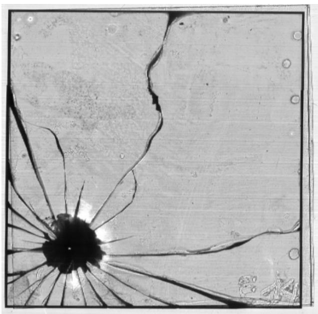
Series (Sample)	Glass type / product	Anisotropy image (line scanner)	Fracture pattern distribution
A (A11)	ANG		No investigation
B (B-14)	HSG		
C (C-13)	TTG		
D (D-15)	CSG		
E (E-14)	NTG		

Fig. 4: Anisotropy images and distribution of the corresponding fracture pattern distribution of one representative samples per series.

3.3. Distribution of fracture pattern

The images of the fracture pattern for series B, C, D and E are illustrated in Figure 4. The purely thermally pre-stressed samples of series B and C show a fine fracture pattern. The fracture pattern of series B is too fine for a HSG according to the requirements of EN 1863-1 (2011). In contrast, the number of fragments for the TTG (Series E) is sufficiently high to fulfil the requirements of EN 12150-1 (2020). Series D (CSG) and E (NTG) exhibit a coarse fracture pattern and rare to no crack branching. The stored energy due to the prestressing processes is too low for the formation of crack branches. An explicit determination of the amount of fragments was not carried out.

3.4. Strength out of coaxial double ring test

The results of the strength test (here coaxial double ring test) are summarised in Table 3. For each series, the expected values (“mean value”) and the coefficients of variation as well as the characteristic strength values (5% fractile value at a confidence level of 95%, two-parametric Weibull distribution) were determined. The estimation function (n+1) according to Weibull (1939) was selected. No outlier test was carried out and all samples with breakage origin within the load ring were used for the determination of the strength values. The expected value for Series A is 140 MPa and serves as a reference value for the comparison here. The results of the thermally pre-stressed series B and C are in the similar range of 241 respectively 252 MPa, clearly exceeding the reference value of series A. There is no real difference between the two series B and C in terms of bending strength. Series D and E show a significantly higher expected values (series D 597 MPa and series E 593 MPa) than the other series. A closer look at the values of series E, however, shows that the scatter within these series is very large due to one value (minimum value of 142 MPa) and therefore the characteristic value is very low compared to the other pre-stressed series B, C and D.

Table 3: Results out of coaxial double ring test.

Glass type	Series	Amount of valid/ total samples	Values				
			Min. [MPa]	Max. [MPa]	Expected value** [MPa]	Coefficient of variation** [-]	Characteristic strength values* [MPa]
Soda-lime silicate glass (SLG)	A	8/10	60	170	140	0.26	49
Heat strengthened glass (HSG)	B	9/10	197	319	241	0.2	156
Thermally toughened glass (TTG)	C	9/10	186	328	252	0.2	163
Chemically strengthened soda lime silicate glass (CSG)	D	10/10	517	681	597	0.12	464
Novel toughened glass (NTG)	E	6/10	142	638	593	0.76	70
Note	* 5% fractile value at a confidence level of 95%, two-parametric Weibull distribution ** based on two-parametric Weibull distribution						

Figure 5 shows exemplary images of the samples for each series after the bending test. There are clear differences (e.g. number of fragments) in the distribution depending on the type of pre-stressing. With an increasing pre-stressing degree, the number of fragments within the load ring increases. This can be explained by the high fracture energy, which increases accordingly with higher strength values.

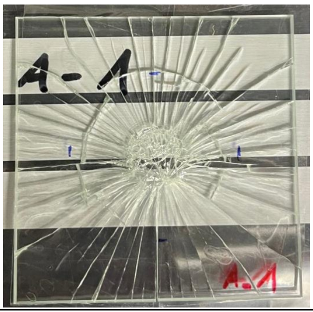
	Distribution of fracture pattern after coaxial double ring test		Distribution of fracture pattern after coaxial double ring test
Glass type ANG series A (sample A-1)		-	-
Glass type HSG series B (sample B-9)		Glass type TTG series C (sample C-6)	
Glass type CSG series D (sample D-9)		Glass type NTG series E sample E-7	

Fig. 5: Distribution of fracture pattern after coaxial double ring test.

4. Discussion and potential

The results of the comparative investigations (see Chapter 3) for the new pre-stressing method are very promising. In this chapter, the potential and existing limitations are critically discussed. The discussion will focus on the novel pre-stressing process and the corresponding results for the novel toughened glass (NTG, Series E).

Glass is chemically or thermally toughened to enhance its load bearing capacity or resistance against breakage. Both methods are well established in industrial practice – chemical toughening for thin and display glass as well as for yacht glazing, and thermal toughening in the automotive and architectural sectors. Despite their advantages, both approaches also exhibit notable limitations (see Chapter 1). The novel pre-stressing method introduced in this paper enables a significant increase in strength by a factor of 2.3 compared to thermally toughened glass (TTG). However, due to the pronounced scatter observed in Series E, the characteristic bending strength value for NTG reached only 43% of the the corresponding value for TTG. Potential reasons include improper handling of the samples during the pre-stressing process or during mechanical testing. The exact causes should be determined and finally eliminated in future work. Zaccaria (2016) also conducted bending tests (coaxial double ring test) using a similar configuration (loading ring radius 15 mm and support ring 51 mm) on various bi-tempered glass series with a nominal thickness of 6 mm. In that study, the process parameters temperature and time were varied. The mean value of bending strengths of these series ranged from 271 to 427 MPa, with a maximum coefficient of variation of 0.38. The mean values in Zaccharia (2016) are below the expected strength value obtained in this study (593 MPa). It should be noted that the mean and expected value of a series are not identical but tend to converge with increasing number of samples. The high strength values are expected to result in a high thermal shock resistance, clearly exceeding the level of conventional thermally toughened glass (TTG). Consequently, this type of glass (NTG) may also be suitable for fire resistant glazing applications.

The measurement of the total pre-stress or residual stress value of Series E was not possible. Only the thermal pre-stress component and its profile could be measured reliably. The measurement of the chemical pre-stress component was without success. The development of a suitable measurement method would be desirable for the purposes of non-destructive quality control and process optimisation. Investigations conducted in collaboration with the manufacturer of the Scalp device were also unsuccessful.

The comparison of the anisotropy measurements of the series shows that significantly fewer anisotropy effects occur for series E compared to the conventional pre-stressing process for architectural applications. This could be caused by the low thermal toughening level of the E series or rather by the homogeneous cooling process in the immersion bath. Furthermore, it is assumed that the vertical alignment in the pre-stressing process results in significantly fewer distortions and optical disturbances (e.g. haze) within the glass panes in contrast to the horizontal thermal pre-stressing process.

The fracture fragment size is more characteristic for an annealed glass and tends to produce sharp-edged fragments. Due to the large fragment size, a high post-breakage performance can be achieved if this type of glass is applied within laminated safety glass.

Further investigations are necessary, especially on standard test geometries, in order to demonstrate the scalability to large glass formats and to assess the reproducibility of the results.

5. Summary and Outlook

5.1. Summary

This paper presented a novel pre-stressing method for flat glass and results in comparison to the classical pre-stressing methods for flat glass. For this purpose, five glass types / products annealed soda lime silicate glass, heat strengthened glass, thermally toughened glass, chemically strengthened soda lime silicate glass and a novel toughened glass were investigated. Non-destructive (residual stress and anisotropy measurements) and destructive (strength and fracture tests) methods were used in the tests to determine the potential of this novel type of glass. Flat glass samples with dimensions of 100 mm × 100 mm and a nominal thickness of 4 mm were used for the tests. The production limitations for the novel glass type NTG did not allow the use of standard glass dimensions for strength and fracture tests (like 360 × 1100 mm² according to EN 12150-1 (2020)).

The results (see Chapter 3) demonstrated that the new pre-stressing method achieves very high strength values in the range of chemically pre-stressed glasses and this with significantly shorter process times (approx. 30 minutes). Furthermore, no anisotropy effects occur in the surface area of these glasses. Nevertheless, the high scatter in the strengths still needs to be reduced to ensure suitability for industrial applications. The fracture pattern is coarse and the strength is significantly higher compared to conventionally thermally toughened glass. As a result, it is recommended to use this glass type as laminated safety glass (LSG) in overhead glazing applications. The post-breakage load bearing capacity will be significantly improved compared to TTG in a LSG built-up. Furthermore, complex glass structures such as multi-curved glass (see Schula and Pritz (2025)) and structurally optimised glass structures (see e.g. Jewett et al. (2025), Seel et al. (2025)) as well as thin glass plates can be toughened due to the process. The toughening process described in this study is essential for the establishing of the mentioned glass applications and promising for fire resistant glazing. Overall, the results emphasise the potential of this new pre-stressing approach for lighter, more efficient and sustainable glass constructions.

5.2. Outlook

The study illustrated the general feasibility and potential of a novel pre-stressing method which combines the chemical and thermal toughening approach. However, the promising pre-stressing method should be further developed and adapted for larger dimensions in the field of architecture. In future, investigations to determine the performance properties (fracture pattern, strength, etc.) should be carried out with standard formats for flat glass (e.g. 360 mm x 1100 mm). Pre-damaged samples with scratches deeper than the chemical compressive stress zone should also be prepared for strength testing. In theory, this approach can also be applied to thin glass (less than 1.5 mm) and complex glass structures. Therefore, the pre-stressing process can be attractive for the automotive sector and for solar glass applications. Furthermore, the question of suitable coatings for the process needs to be addressed. The legal requirements for use, primarily in the construction industry, must be clarified, because the process is not state of the art and there is no product standard for this type of glass.

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