Glass improvement by combination with plastics[1])

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After a short survey of the development of laminated safety glass, modern safety and comfort requirements are listed. Problems and properties of such glass-plastic combinations are examplified by the Sekuriflex windshield. In addition, other functions and solutions for security glazings as well as antifogging by moisture and impact resistance are discussed. Fireproof and sound insulating glazings are discussed on the basis of symmetrical glass-plastic combinations with both exterior faces consisting of glass.

Glasveredelung durch Kombination mit Kunststoffen

Nach einem kurzen Überblick über die Entwicklung des Verbundsicherheitsglases werden die modernen Sicherheits- und Komfortansprüche aufgezählt. Am Beispiel der Sekuriflex-Windschutzscheibe werden die Probleme und Eigenschaften solcher Glas-Kunststoff-Kombinationen dargestellt. Darüber hinaus werden weitere Funktionen und Lösungen für Ein- und Ausbruchhemmung, Beschlaghemmung und Beschußhemmung diskutiert. Als symmetrische Glas-Kunststoff-Kombinationen, bei denen die beiden Oberflächen aus Glas bestehen, werden Brand- und Schallschutz-Verglasungen erläutert.

1. Demands on laminated safety glass

Safety glass consisting of two glass panes connected by an interlayer had been patented as early as 1905 by Wood in England. Industrial development of glass improvement by combinations with plastics started with the invention by Benedictus in France to laminate two glass panes with a celluloid layer in order to prevent flying splinters in the case of fracture. Subsequently celluloid, which was subject to aging, was replaced by nitro- and acetyl-cellulose, then by the polymerization products cellulose acetate, acryl compounds, polyvinyl acetate, until finally polyvinyl butyral produced permanently satisfying solutions [1]. Today laminated safety glass is produced and applied worldwide using polyvinyl butyral. Its properties are sufficiently known.

The two principal markets of safety glass are the automotive sector and the building sector. Apart from the basic demands of light transparency and freedom from optical distortion, additional demands originate in various areas of application. Thus, for instance, a green glass provides some protection against sun rays. Table 1 lists protective properties of so improved products known for a long time. Depending on the type of combination, such protective effects are given to a greater or lesser extent. If further performance requirements are needed, glasses will have to be coated and/or combined with plastics. Glass-plastic combinations may fulfill a multitude of safety and comfort requirements; the most essential of which are:

- protection against cutting injuries,
- protection against flying splinters,
- protection against impact of stones,
- controlled energy absorption,
- protection against burglary and ejection,
- protection against attack and shooting,
- fire protection,
- antifogging properties,
- protection of coatings against corrosion and mechanical damage.

2. Some glass-plastic combinations and their properties

As a protection against cuts and splinters in the case of fracture the Sekuriflex windshield was developed at Vereinigte Glaswerke GmbH, Aachen (FRG). As is known, it consists of a laminated safety glass which is coated additionally at the inner side by a poly-

Table 1. Protection effects

	fracture resistance	protection against		
		sun	heat	sound
insulating glass		×	×	×
toughened glass	×	×		
laminated glass	×	×		×

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[1]) Presented in German on 29 September 1988 at the DGG/HVG Colloquium "Veredelung von Glasoberflächen – Finishing of Glass Surfaces" in Düsseldorf (FRG).

Table 2. Abrasion and impact resistance

	abrasion resistance [4], Taber abraser²) increase of haze in %	sand drop resistance [5], increase of haze		micro scratch hardness³) in N	scratch hardness²) [6] in N
		in cd/m²	in %		
float glass	0.4 to 1.1	– 4.3	5.4	0.08 to 0.16	0.10 to 0.12
Securiflex 1	1.8 to 6.0	0.6 to 1.5	1.4 to 1.8	0.2 to 0.24	5.6 to 5.9
polycarbonate	38	23	30	0.02	
PolyMetaMethylAcrylate (PMMA)	30	20	29	0.03	0.25
cellulose acetate	30	20		0.03	0.25

²) Taber, Teledyne Comp., North Tonawanda, NY (USA).
³) CWH Erichsen GmbH & Co., Hemer-Sundwig (FRG).

urethane foil (Sekurex). It is not necessary to reiterate the excellent service properties of Sekuriflex which have been proven in test series as well as in the field [2 and 3]. The polyurethane foil used here consists of a softly conditioned thermoset, which due to its elasticity is self-healing when scratched, and of a thermoplastic layer effecting the adhesion to the glass.

Plastic foils of the high optical quality as required for flat glass could not be found in the market. Nor were attempts to improve optically less satisfactory foils by a suitable overlay procedure satisfying. Therefore, the development of new techniques was required. The ample experiences in flat glass production contributed significantly to the solution of this problem.

In the author's opinion only the casting process was suited to prepare optically high-performance foils. The single process steps such as raw material preparation, admixture of additives, mixing of components, supportive preparation, casting, polymerization control, posed specific demands. In addition, the entire device had to be maintained absolutely dust-free. Similar adaptations were necessary for the assembling techniques.

Obviously this Sekurex foil is not restricted to laminated safety glass. It can also be used to enhance safety properties of raw glass, toughened glass, mirrors, eye glasses. If overlaid on plastics it provides improved scratch-, abrasion-, and corrosion resistance. The thermoplastic adhesion layer of Sekurex also permits overlaying of metal or metal oxide layers produced on glass by vacuum deposition or pyrolysis, which thus are protected against corrosion and mechanical damage.

Scratch resistance of Sekurex can be controlled since it easily yields under punctual load and reshapes after release. This behavior is particularly beneficial in the case of impact by sand or similar hard particles of high velocity. Glass overlaid with Sekurex thus can be called sand blast-resistant. Table 2 presents a comparison of abrasion and impact resistance for float glass, Sekuriflex, and some plastics. In the same way stone-impact resistance of glass can be increased by such an exterior coating. Table 3 gives an example:

Table 3. Stone impact resistance of differently treated head lamp

head lamp treated with	secure fracture limit in km/h at environmental conditions of		
	23 °C and 50 % relative humidity	40 °C and 35 % relative humidity	−10 °C
Sekurex foil ≈ 350 μm coated	160	145	150
UE foil 60 to 100 μm sprayed	95	95	95
no coating	55	55	55

the resistance of a head lamp glass against stone impact simulated by a 6 mm diameter steel sphere.

The functions of the soft plastic foil described so far (cut protection, corrosion resistance, stone-impact protection, etc.) will be realized if the property values listed in table 4 are met. A controlled absorption of energy, as required, e.g. in the case of a head impact on the windshield, can be met by a plastic foil with properties also listed in table 4. Absence of softener and solvent is advisable for plastics located at the surface.

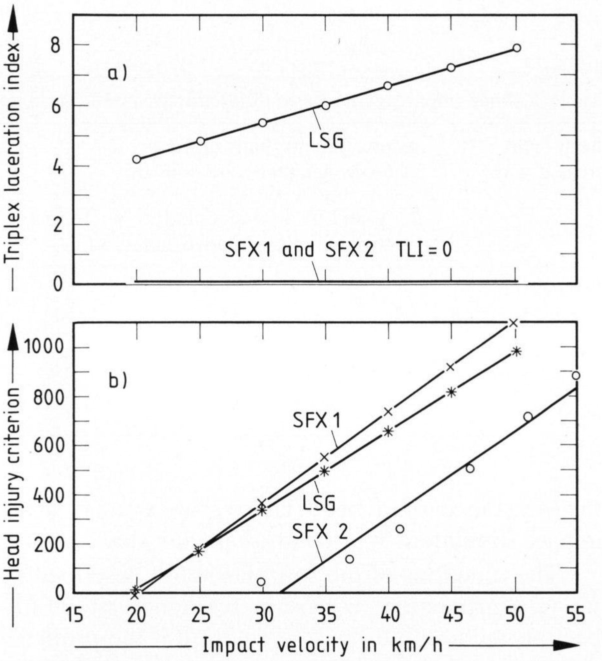
The combination of a glass pane (≈ 3 mm thick) with such an energy-absorbing plastic foil (≈ 0.7 mm thick) made scratch resistant with the soft polyurethane foil as described represents a nearly ideal windshield. Figures 1a and b give the comparative biochemical data [7 and 8].

The same combination of foils overlaid on toughened glass represents an interesting safety pane, e.g. for automotive side glazing. If the body impacts the plastic on the inner side of the comportment it is protected against laceration and the occupant is contained within the vehicle. If the glass side is impacted, the glass particles are held together, act like a barrier and may, in concert with the foil, resist intrusion. Figures 2a and b demonstrate this behavior.

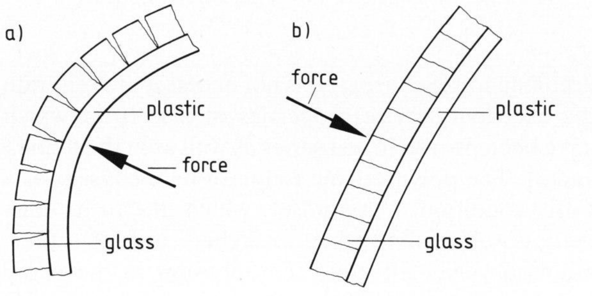
Another interesting glass-plastic combination is bulletproof glass. It serves to attenuate the impact energy of the missile to the point that the missile becomes stuck and no splinters separate from the reverse side. This is achieved generally in a laminated

Table 4. Material data

soft plastic foil on laminated safety glass		energy-absorbing plastic foil	
fracture dilation in %	>100	fracture dilation in %	250 to 500
fracture stress in MPa	≈ 10	fracture stress in MPa	> 20
mean elastic modulus in MPa	≈ 20	stretching strain in MPa (at −20 °C)	< 30
dilation until fracture in %	< 2	resistance to continued fracture in N/mm	> 90
modulus of elasticity in MPa	≈100		
haze through thickness used in %	< 0.5	haze through thickness used in %	< 0.5
neutrality of color		neutrality of color	
absence of softener and solvent		absence of softener and solvent	



Figures 1a and b. Risks of injury versus impact velocity; a) Head Injury Criterion (HIC), b) Triplex Laceration Index (TLI) [9]. LSG = Laminated Safety Glass, SFX 1 = four layer windshield, SFX 2 = bilayer windshield.



Figures 2a and b. Protection against burglary and ejection; a) ejection situation, b) burglary situation.

glass consisting of a suitable number of glass panes. Thus, e.g., a bulletproof glass step C_4 [10] is up to 65 mm thick weighing about $160 \cdot 10\ N/m^2$.

Now the impact resistance of PolyCarbonate (PC) can be utilized to produce a corresponding bulletproof glass by combining laminated glass with polycarbonate. A remaining problem is the difference in the two coefficients of thermal expansion. This problem can be solved completely by means of an interlayer of thermoplastic polyurethane of suitable thickness. The insufficient scratch resistance of PC may be overcome, e.g. by coating with the Sekurex foil. Such a glass-plastic combination is only 37 mm thick weighing $80 \cdot 10\ N/m^2$.

3. Antifogging glazings

Based on the Sekuriflex technology a foil material was developed which is antifogging in addition to the safety aspect as well as to useful scratch and abrasion resistance. This effect was achieved by adding to the basic components, during the preparation of the foil, wetting agents permanently remaining in the foil. This combination has the effect that condensing water is not – as usual – forming a haze on the glass or plastic surface.

The phenomenon of moisture condensation below the dew point cannot be prevented even by Sekuriflex Antifog. However, water condensing on the surface of the foil is supplied with controlled amounts of wetting agents so rapidly that, because of the temporarily decreased surface tension, no water droplets are formed. Rather, a very thin and uniform water film will form immediately. In practice this means vision is not disturbed by condensation. This spreading effect can be represented by the contact angle of water on the respective substrates. Figure 3 compares Sekuriflex Antifog with glass and plastics.

The foil can be deposited on glass – laminated or toughened glass, mirrors, etc. – or plastic.

4. Symmetrical glass-plastic combinations

The combination of glass and plastic discussed so far had one surface consisting of glass, the other of plastic. Another category involves combinations with plastic interlayers. Besides the standard laminated safety glass, there are fire protection glazings and acoustical damping glazings.

If fire protection glazings are only to prevent the spread of fire and gas (fire resistance classes G), but also to prevent heat transfer (fire resistance classes F), a heat shield must be inserted between the glass panes. Water, which consumes large amounts of

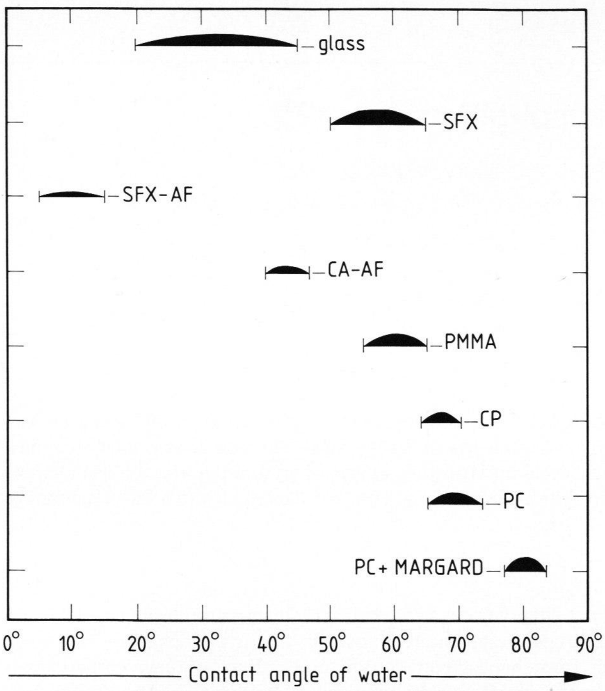
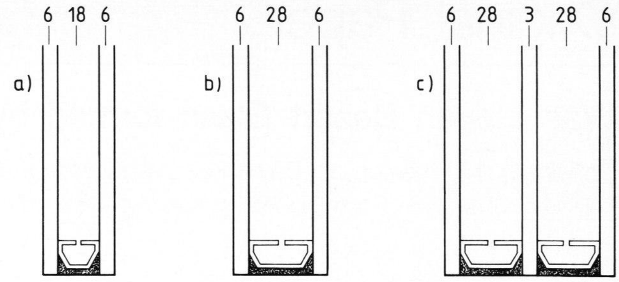


Figure 3. Contact angles of water on various substrates.



Figures 4a to c. Examples for fire protection glazings with different fire resistance classes [11], a) F 30, b) F 60, c) F 90. The numbers 3 and 6 represent the glass thickness, the numbers 18 and 28 the thicknesses of the interspaces in mm.

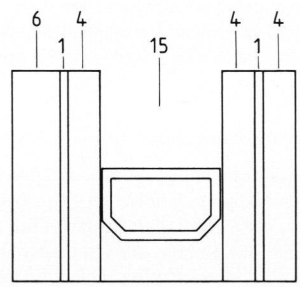


Figure 5. Sound insulating glass. The numbers 4 and 6 represent the glass thicknesses, the numbers 1 and 15 the thicknesses of the interspaces in mm. (Evaluated sound insulating factor $R_w = 46$ dB.)

energy on evaporation, is suitable. However, water should not exert any hydrostatic pressure on the panes which form the boundaries. Therefore, water is embedded in a gel formed from a polymer. Depending on the number of interspaces, durations up to 120 min can be obtained. Figures 4a to c show such solutions [11].

Modern sound insulating glasses are constructed according to the principle of unequal pane thicknesses, of elastic pane combinations and of damping interspaces. The latter are best filled with a heavy gas. At least one of both glass units is a laminate with a specific plastic foil or casting resin in such a way as to decouple the single panes. Figure 5 shows a realization.

5. Conclusions

The examples described show that glass-plastic combinations have properties not attained by either glass or plastic. Only their combination permits the addition of advantages and the compensation of disadvantages.

Improved products are usually multifunctional glazings of a very high quality level. Therefore, as a rule, only high-quality plastics are used. Very frequently new production and finishing techniques must be developed to meet various requirements of glass and plastic.

Finally, introduction to the market place must be preceded by an extensive testing program which should comprise not just simulation of the target function but also general service properties.

6. References

[1] Jebsen-Marwedel, H.: Tafelglas. Essen: Girardet 1950.
[2] Patrick, L. M.; Chou, C. C.: Safety performance of Securiflex windshield. In: Proc. 20th Stapp Car Crash Conference, Warrendale, PA (USA) 1976. New York: Soc. Automotive Engrs. 1978.
[3] Jandeleit, O.; Orain, R.: Performance of a non-lacerative windshield in case of accident and under environmental conditions. In: International Automotive Engineering Congress and Exposition, Detroit, MI (USA) 1977. New York: Soc. Automotive Engrs. 1977. (SAE Paper 770246.)
[4] German standard DIN 52 347 (December 1987): Prüfung von Glas und Kunststoff; Verschleißprüfung, Reibradverfahren mit Streulichtmessung. Berlin: DIN 1987.
[5] German standard DIN 52 348 (February 1985): Prüfung von Glas und Kunststoff; Verschleißprüfung, Sandrieselverfahren. Berlin: DIN 1985.
[6] German standard DIN 53 799 (January 1986): Platten mit dekorativer Oberfläche auf Aminoplastharzbasis; Prüfung. Berlin: DIN 1986.
[7] Doolittle, E. P.; Horton, T. B.; Blom, H. P.: Anti-lacerative windshield materials//Field evaluation by General Motors. In: International Congress and Exposition, Detroit, MI (USA) 1984. Warrendale: Soc. Automotive Engrs. 1984. (SAE Paper 840391.)
[8] Versaie, J.: A review of the severity index. In: Proc. 15th Stapp Car Crash Conference, Coronado, CA (USA) 1971. New York: Soc. Automotive Engrs. 1971.
[9] Pickard, J.; Brereton, D. A.; Hewsen, A.: An objective method of assessing laceration. In: Proc. 17th Conference Am. Assoc. Automotive Medicine, Oklahoma City, OK (USA) 1973.
[10] German standard DIN 52 290, pt. 2 (November 1988): Angriffhemmende Verglasungen; Prüfung auf durchschußhemmende Eigenschaft und Klasseneinteilung. Berlin: DIN 1988.
[11] German standard DIN 4102, pt. 2 (September 1977): Brandverhalten von Baustoffen und Bauteilen; Bauteile, Begriffe, Anforderungen und Prüfungen. Berlin: DIN 1977.

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