Aging aircraft transparencies: a case history from Italian Air Force Fleet.

Lt.Col. Manuele Bernabei, Lt. Daniele Caucci, Capt. Lorenzo Aiello*
Italian Air Force Flight Test Center
Airport M. de Bernardi
rc.gms@tiscali.it

Summary

Aircraft acrylic transparencies are structural components that must withstand flight and ground loads; crazing occurrence is one of the most common causes of their substitution during aircraft maintenance operations. This form of aging, or Environmental Stress Cracking (ESC), is mainly a physical phenomenon due to the interaction of transparencies based materials with an active liquid to cause craze formation at lower stress that would be required in air; the stress values are temperature dependant and correlated to both transparency's void and entanglement density.

In this paper, we investigated an extensive phenomenon of network ESC occurred on transparencies of many aircraft operating in the same fleet, causing their replacement well before the required service life. Cover application while parking has been individuated to be the critical aspect in crazing appearance, acting as physical shield for condensed water and heat transfer.

Introduction

Aircraft transparencies (windshields, canopies and windows, Fig. 1) are structural components that must withstand flight and ground loads; nevertheless, like metal airframes, they are subject to aging with attendant reductions in structural capabilities, generating warnings related to aircraft safety as well as operational readiness [1].

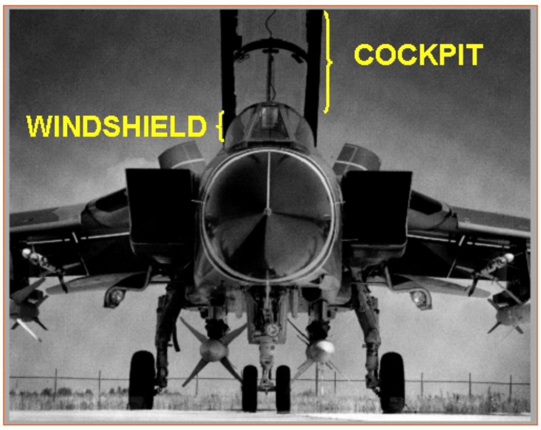

FIGURE 1. Fighter aircraft transparencies.

* Corresponding author.

Windshields and windows commonly used for building purpose are glass, polymethyl-methacrylate (acrylic), polycarbonate, or interlayer materials. Performance and design of these materials have to be considered critical issues in their aeronautics application. In particular both basic forms of acrylics (cast material and biaxially stretched material) based on unplasticised methyl-methacrylate polymers have been often used in aircraft transparencies due to their good forming characteristics, optical features and outdoor weathering behaviour.

Amorphous glassy polymers, such as acrylics, are softer and tougher than glass; mechanical properties of this class of polymers are reduced by temperature improvements, with except of elongation and impact properties. They are subject to a yield mechanism termed "crazing" featured by formation of long elongated voids within the material by a tensile cavitation process. The voids shape (or crazes), tend to be perpendicular to surface, with narrow thickness (1000˚A) and less than 250 microns in depth. At a visual examination they seem to be like a conventional cracks. The difference with cracks are in the broad faces of the crazes spanned by a large amount of elongated fibrils drawn from the polymer as the craze opens.
Furthermore, crazing is induced by exposure to organic fluids and vapours, such as alcohols, aromatic and chlorinated hydrocarbons, carbonyl compounds (as some hydraulic fluids) or by prolonged exposure to surface residual tensile stresses (caused by poor forming practice, machining, polishing, or gouging and prolonged loading) above a critical level [2]; crazing stress has been confirmed to be temperature dependant, correlating it to both void and entanglement density [3].

Acrylics base transparency undergo this kind of crazing. The chemicals effect consists in a severe worsening of mechanical properties. Moreover, on brittle materials such as acrylics, further development of crazing will result in crack and rupture.

For these reasons residual stresses are avoid during manufacturing operations, and maintenance operators have been tasked to use only washing products which are not aggressive at all. Nevertheless, one of the most common causes of substitution of aircraft transparencies is still crazing occurrence. This form of aging, defined Environmental Stress Cracking (ESC), can be mainly considered as a physical phenomenon due to the effect of an active on transparency base materials: in these conditions crazing occurrence is featured by stresses lower than those required in air [4]. The principal cause of ESC formation is generally related to surface plasticization, due to the diffusion of a liquid from environment into the material: it produces a localized reduction factor in yield strength, promoting an easier craze evidence. Water diffusion is particulary significative on ESC occurrence for its small molecular size although does not seem to have a toughening effect on the growing crazes; in acrylic materials, crazing stress values decrease as the amount of absorbed water increases (0.01-1.40 % range), and its density increases with applied stress [5]. Confirming the plasticization effect, at water concentration 1% the strain fracture is three times higher and the stress at fracture is one half of the dry value [6].

In this paper, we investigated an extensive occurrence of crazing and subsequent network cracking on transparencies of many trainee ultrasonic jet aircraft, promoting their substitution well before of their required service life because of pilot's flight visibility lack.

Case history and background

Trainee ultrasonic aircraft fleet has been renewed in last five years and it is operating on an Air Force Base in the south of Italy. In this period ESC phenomena on transparencies of many vehicles has been observed. It has been necessary to replace parts well before of their required service life because of flight visibility lack, fig. 2, causing money waste and delay in flying readiness.

Original Equipment Manifactorer (OEM) requires that whole cockpit should be protected by means of application of a cover during long term no fly period. That's because flight instruments and controls may be severely affected either by heat transfer due to sun irradiation and by water infiltration due to night condensed moisture.

The required washing procedures, during on service maintenance, supposed to be not aggressive at all, have been confirmed to have been executed.

All damages were placed only on cockpit double transparencies, saving the windshield, and they were localized on central/right area, fig. 3.

Figure 2.

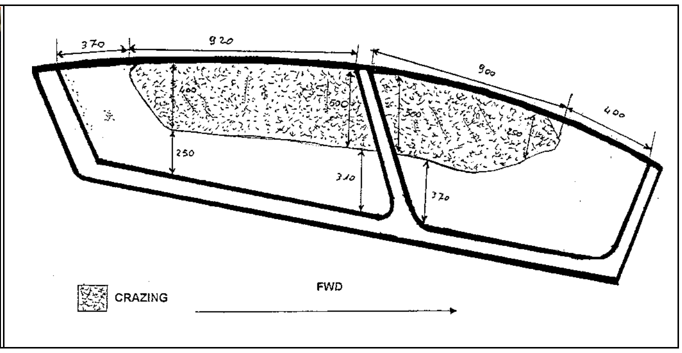

Figure 3. ESC localization

Back transparency shows on left side superficial damages as scrapes but they did not act as initiation for ESC phenomena, fig. 4. Instead, on the right side, scrapes are stress concentration factors causing dense crazes, although there are many crazes even without initiation, far away from scrapes; a large part of damaged surface shows network of cracks with typical morphology of flat mug, fig. 5.

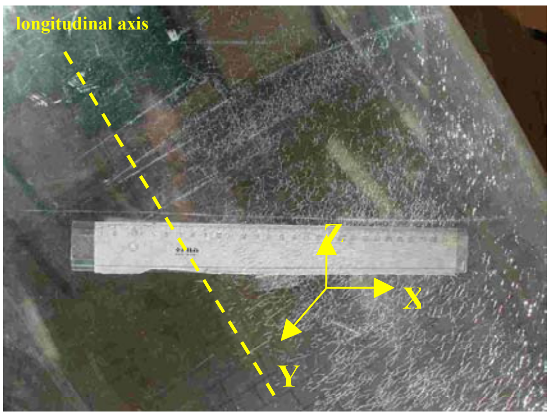

Figure 4.

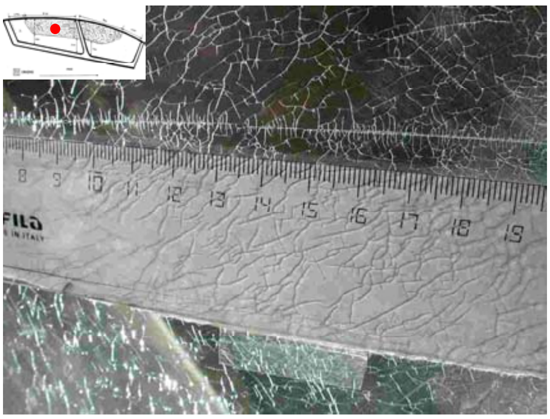

Figure 5.

Simple crazes are present on central area of the front transparency: each of them is perpendicular to longitudinal axis, fig. 6. The remaining damaged area it is not featured by a preferential direction of craze propagation, fig. 7; only a little zone shows a morphology of degradation which is typical of accidental contact with an aggressive liquid, fig. 8.

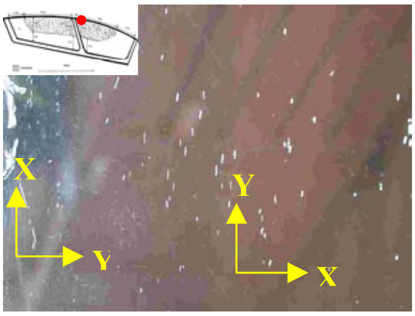

Figure 6.

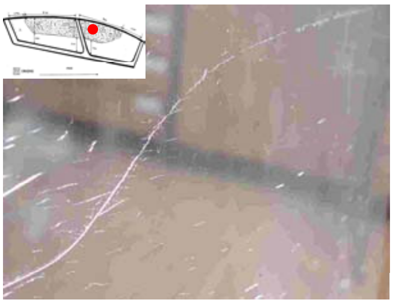

Figure 7.

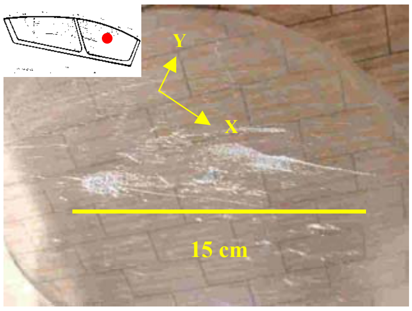

Figure 8.

Experimental

Materials

Aged transparencies have been evaluated, by means of comparison with standard sheets compliant with MIL-PRF-5425-E. Three covers applied an trainee aircraft.

Methods and Instrumentations

Infrared spettrometry (FTIR) on covers and transparencies, by means of FT-IR PE spectrum 1000. Pyrolysis - Gas Chromatography (GC-Pyr) on covers and transparencies, by means of GC PE 8700 (column VB-1 and FID detector) and CDS Instruments Pyroprobe 1000. Tensile properties of transparencies have been tested by ASTM-D-638, using the SCHENCK RM 250 apparatus. Software Algor has been applied to execute Finite Element Model (FEM) thermo-mechanical analysis.

Diffraction analysis (RX) has been carried out by RIGAKU D-MAX GEIGER-FLEX Diffractometer Thermal measurements have been carried out by means of ASTM-E-1213, using the IR camera CEDIP JADE III and thermometer RAYTEK Ranger 3i. ASTM F 484 and ASTM F 791 have been applied in stress cracking tests performed on investigated transparencies and standard PMMA sheets.

Results and Discussion

Transparencies conformance to MIL-PRF-5425-E specification has been confirmed, at first by determination of acrylics nature by means of FTIR and GC-Pyr. RX showed that damaged and undamaged surfaces share homogeneous structural order, thus local heat treatment gone wrong has been excluded.

Aged transparencies ultimate tensile strength values measured in undamaged areas were lower than standard specimens because of natural aging but above of the required minimum value (55 Mpa); tensile strength values of specimen from damaged area were about 70% less than specimen in undamaged area, confirming safety concerns as warning to promote parts replacement.

Crazing formation on aged transparencies has been tested by means of ASTM F 483, to evaluate the effect of the application of an aggressive solution by a wetting filter paper on a aged transparencies specimen; as results, crazing occurrence has been related to the temperature and the composition of the aggressive solution wetting the filter, Table 1. Moreover high temperature effect on aged transparencies might be sufficient to promote crazing even if not associated to aggressive environments.

TABLE 1. Stress crazing stress on aged transparencies

Ethanol/ water v/v	**50/50**	**50/50**	**50/50**	**60/40**	**0/100**
Stress at fulcrum (Mpa)	17.6	18.5	17.3	17.4	17.4
T (°C)	20	30	40	20	60
t (min)	60	20	10	40	140
Crazing density	single	single	multiple	multiple	single
Crazing localization	body	body	body	body	body

Different multilayer covers have been evaluated by GC-Pyr and FTIR: their composition has been confirmed to be silicon-PVC based and polyester-PVC based; hot water immersion did not allow to individuate extracted agents able to be aggressive against polymethylmethacrilate, by means of their application as wetting agents of filter paper during ASTM F 791 procedure.

Thermographic analysis have been carried out to measure the effect of sun irradiation and to evaluate transparencies behaviour while staying under covers used on aircraft. Heat transfer has been carried out by means of a 4000 W lamp at 25 cm, and temperatures have been measured on internal and external surfaces until constant values, figure 9. Low thermal diffusion of acrylic materials seems to be a critical aspect: a sharp temperature gradient is observed out of heat incidence, with loss of 30 °C in less than 20 cm.

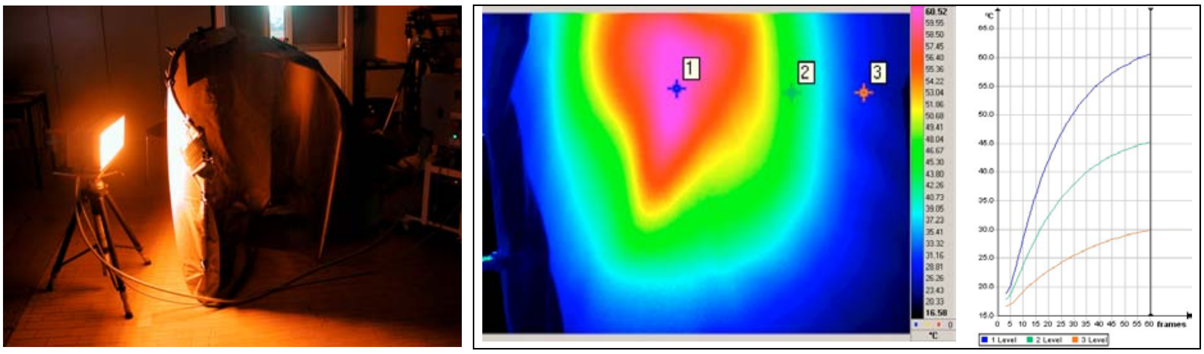

Figure 9.

FEM of a thermo-mechanical analysis has been produced to assess surface stress related to temperature gradient: after a 30 minutes heating, the highest value of principal stress was about 14 MPa, about 20 % of ultimate tensile strength value measured on aged acrylics specimen in undamaged area.

Conclusion

The work has been focused to understand the causes of crazing like degradation for many acrylic based transparencies constituting canopies of trainee ultrasonic aircraft and to propose few solutions to fleet maintenance management.
Cover application has been individuated to be a significative aspect in crazing appearance. The exposure of standard acrylics specimen to solutions obtained by hot water extraction of different covers samples did not show any crazing promoting. Cover has been supposed to act as physical shield for environmental agents such as night moisture: its evaporation is not allowed with a progressive formation of condensed water on the transparencies. This effect is combined with the daily sun irradiation resulting in cover heating and local acrylics overheating. The combined effect of heat and moisture on low thermal conductivity materials such as acrylics (transparency) and silicon-PVC/nylon (cover) do not allow to the whole particular to share the same temperature and causes a localization of internal stresses. Parking area latitude (N 40°) and aircraft magnetic heading while parking (055° NE) is coherent with the phenomena area on the whole cockpit.
The observed deterioration can be defined as Multi Site Environmental Stress Cracking, and it might be avoided by using an under-transparency cover, or by means of shelters, or adopting a sun infrared irradiation reflective cover, or – at last – creating an air chamber between cover and transparencies.

Acknowledgements

The authors are grateful to the following for their helpful support and assistance:
Marco Mezzana , Italian Air Force, Flight Test Center, Chief of the Chemical Department;
Enrico Dati, Ferdinando Dolce and Giovanni De Angelis, Italian Air Force, Flight Test Center, Chemical Department, for their scientific contribution and inputs to this report;
Paolo Chini, Italian Air Force, Flight Test Center, Chemical Department, for his high valued and fundamental contributions to the trialwork.

References

1. Bouchard M.P., Bowman D.R. and Whitney T.J., *Proceedings of the Second Joint Conference on Aging Aircraft*, 1999, 91-100.
2. *Windows and windshields*, US Dept. of Transportation - Federal Aviation Administration, Advisory Circular No: 25.775-1X, Draft 6/11/01.
3. Yamamoto T. and Furukawa H., *Polymer*, vol. **36**, 2393-2396, 1995.
4. Arnold J.C., *J. Mat. Sciences,* , vol. **33**, 5193-5204, 1998.
5. Okoi Y., Ishiyama C., Shimoyo M., Shiraishi Y., Higo Y., *J. Mat. Sciences*, vol. **35**, 5001-5011, 2000.
6. Hamouda A.M.S., *J. Mat. Proc. Tech.*, vol. **124**, 238-243, 2002.