Thermal Inertia of Composite Glider Wing Structure, and the JAR-22 Strength Requirements

Miroslaw Rodzewicz
Warsaw University of Technology
Nowowiejska 24, 00-665 Warsaw, POLAND
miro@meil.pw.edu.pl

XXVII OSTIV Congress, Leszno, Poland, 2003

Abstract

The paper presents the results of experimental work aimed in investigation of the time-constants of a cooling or heating process of the PW-5 glider wing. Thermo-couples, located in the most representative part of the wing, combined with a computer-aided measurement system were used. The results obtained include charts of temperature histories of the heated glider components. These permit the value and reliability of strength test methods employed by the glider producers to be evaluated. They also help to justify the JAR-22 requirements for the thermal protection of the glider structure.

Introduction

A well known property of the polymer composites consists in the deterioration of mechanical characteristics (i.e. strength and stiffness) as the temperature increases. The most important parameter, which determines how the intensity of its mechanical characteristic change, is the glass transition temperature T_G. In duroplastics (the epoxy resin belongs to this group) it is the temperature value at which transition from the hard to glass-like state takes place. After reaching T_G, the matrix strength drops considerably. Sample diagrams of mechanical properties of composites versus the temperature are shown in the Fig. 1 and Fig. 2. Generally, we can conclude, that the nature and intensity of mechanical property changes depend on the kind of composite structure, type of matrix and thermal profile of hardening cycle. A consequence of the thermal effect on mechanical properties of composites are the requirements imposed on thermal protection of a glider structures (white colors of the gliders), as well as the necessity for certification tests at elevated temperatures.

In Europe all requirements concerning the glider certification were defined in the JAR-22 Regulations [1]. The most important point referring to mechanical and temperature properties of the composite is JAR-22.613 (JAR-22, Subpart D, Design and Construction): JAR 22.613 - Material Strength Properties and Design Values:

(c) Where the temperature attained in an essential component or structure in normal operating conditions has a significant effect on strength, that effect must be taken into account.

This point is supplemented by the following interpretation text: IEM 22.613:

(c) Temperatures up to 54°C are considered to correspond to normal operating conditions.

In practice, it means that the strength of all elements of primary-structure must be tested at a temperature of 54 deg C (129.2 deg F).

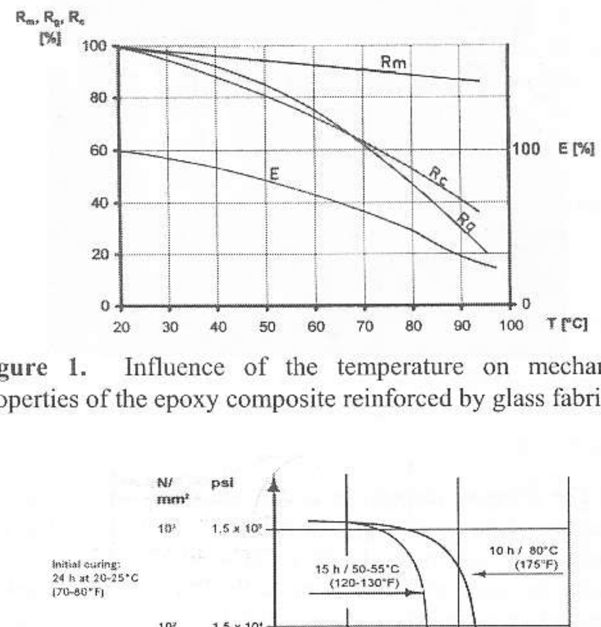

Figure 1. Influence of the temperature on mechanical properties of the epoxy composite reinforced by glass fabrics.

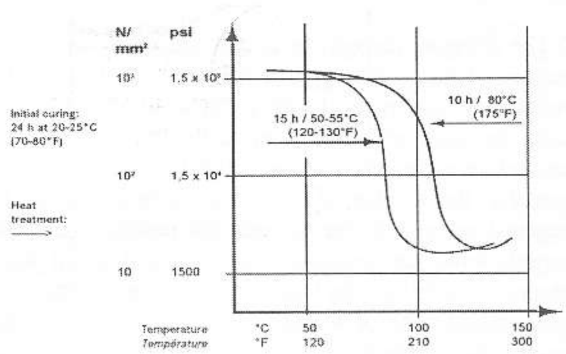

Figure 2. Change of G-modulus versus the temperature of epoxy resin L160 with the hardener 260S [2].

Methods for strength tests performed at elevated temperatures

There are two types of strength tests of glider structures: those performed on specimens of glider structure, and integral tests performed on complete parts of a glider.

The tests on specimens of glider structures are performed at the stage of design (to collect the data necessary for further calculations of the glider strength), as well as at the stage of manufacturing (for technological process supervising). At the stage of design, the tests mainly deal with the joints of concentrated force introduction and the specimens of basic structures (for example, spar flanges). The tests are performed to gather the information about the strength of the designed structure, that result from the application of specific materials, or a particular technological process performed in a specific workshop. At the manufacturing stage it concerns the specimens, called *specimens-witnesses*, which have been made each time when manufacturing a crucial part of the glider structure (again, for example, spar flanges). The strength test on those specimens must prove that the material properties of the wing spar are not worse then those made in the glider strength calculations.

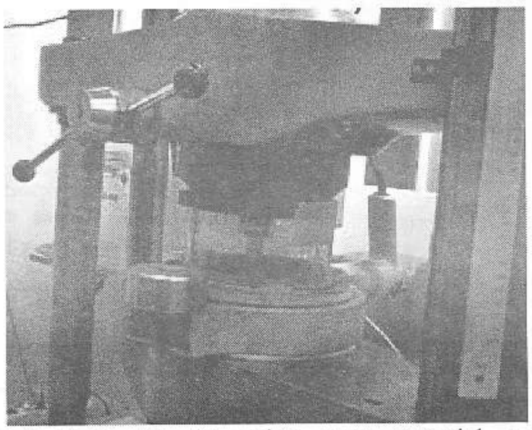

Figure 3. Tests of the wing spar material specimens performed on the strength machine at a temperature of 54 deg C.

The integral strength tests that are performed precede the issuance of the glider type certificate. In all cases the proof strength tests are made at a temperature of 54 deg C.

In the case of small specimens the tests are made on standard strength machines adapted for thermal investigation. Normally, the number of specimens is large enough to enable statistical analysis of the strength test results. To speed up the strength tests, the specimens are warmed to 54 deg C in a separate oven before the test. Then each specimen is moved to the operation zone of strength machine equipped with a small thermal box, which allows for maintaining the specimen temperature until the end of the test (i.e. the moment of specimen damaging).

The integral strength tests at an elevated temperature need large thermal chambers with enough space to contain the tested object together with the system of loading.

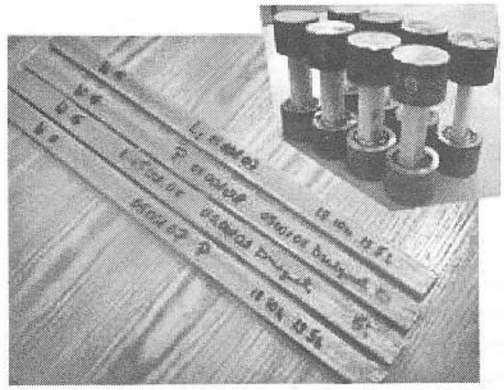

Figure 4. Specimens of composite used for examination of the glider spar flange manufacturing process (witness-specimens) in a raw form and ready for the strength (compression) test, respectively.

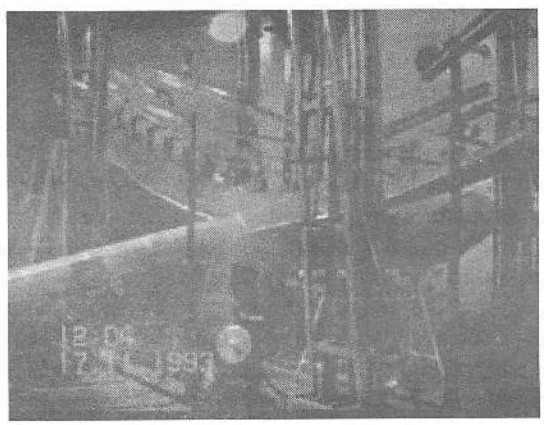

Figure 5. Static strength test of the PW-5 glider at elevated temperatures performed in a large thermal chamber.

Such a facility was applied by one of the major producers of gliders, PZL-Bielsko. This facility ensures that during the whole time of the strength test, the glider structure temperature is stabilized at the level required by the JAR-22.

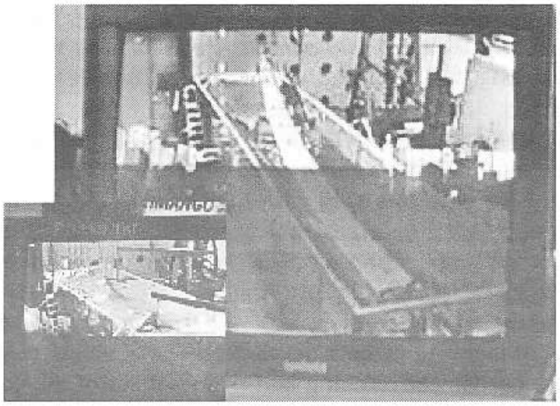

Figure 6. Simplified method of static strength test performing at an elevated temperature (photo taken from the TV monitor).

Some glider manufacturers apply different systems, in which the object is previously warmed up in a small container and is then quickly tested at room temperature. It is assumed that the tested object will not cool down significantly before the end of the test. Such a practice had motivated the investigations to determine whether or not this way of performing the strength test is reliable.

Experimental investigation of the cooling process of a glider wing structure

The structure chosen on which to conduct these tests was a piece of a wing of the PW-5 glider that was 3.3 m long. The structure of PW-5 is typical of many present-day gliders, made of–fiberglass epoxy composites. The cross-section of such a wing consists of the sandwich-type shell and the wing spar.

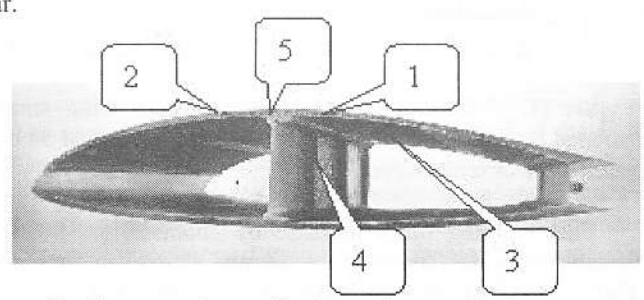

Figure 7. Cross-section of the wing and thermocouple sensors locations:

1. thermocouple sensor in the external skin
2. thermocouple sensor in the external skin (black color of the surface)
3. thermocouple sensor in the internal skin
4. thermocouple sensor in the stiffener of the shear spar web
5. thermocouple sensor in the spar flange

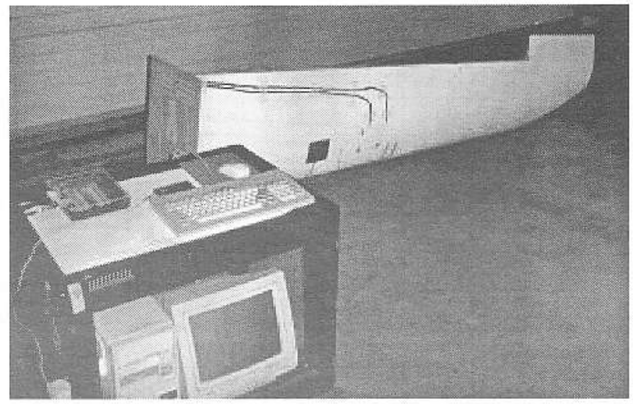

Figure 8. General view of the wing specimen and the system of temperature recording.

The wing spar flanges are reinforced by fiber-glass (roving). Before the start of experiments the specimen was equipped with 5 thermo-couples located at the most representative parts of the wing. The specimen and locations of the thermo-couples are shown in Fig. 7.

K-type thermocouples were used in experiments. The wire diameter was 0,5 mm (0.0196 inch). The cross-sectional area of spar flange at the thermocouple location was about 88 sq. mm. The interior space of the wing was isolated from the surrounding by a special cover fixed to the base of the wing. This cover prevented air from being convected between the ambient space and the caisson of the wing.

A PC-type computer equipped with an analog–digital card and a special card for thermo-couples measurement PCLD-889 made by Advanech (USA) was used for temperature recording.

Experiment number 1: Investigation of the cooling process of the wing structure

After the specimen was warmed to a constant temperature of 54 deg C, it was removed from the heating chamber and exposed to an ambient temperature of 20 deg C. The cooling process is recorded in Fig. 9. It can be seen that the external layers of the wing skin demonstrate the smallest thermal inertia, while the wing spar has the largest. The doubling time (in this case it is the time needed for reaching half of the effect of the cooling process) is approximately: 350 sec for the wing skin; 900 sec for the spar flange.

The decrease of temperature is very fast, and for example the level of 50 deg C is reached by the wing shields after 100 sec and by the spar flange after 300 sec. Thus, it becomes clear that it is very difficult to perform a static strength test of the wing with excessive cooling of the structure. The time of the static test is about 3 – 5 min, so during this period the elements of the wing structure may experience a significant decrease in temperature.

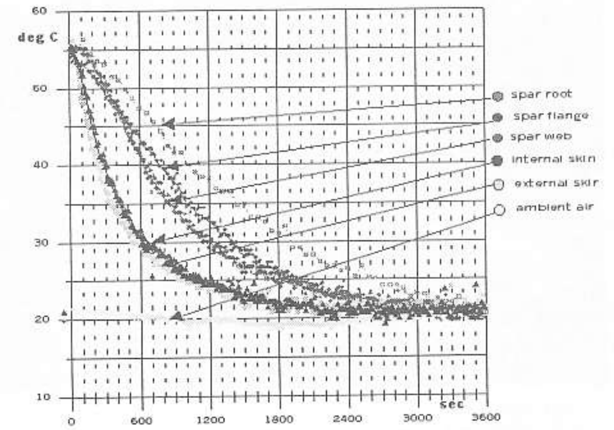

Figure 9. Cooling process of the PW-5 wing structure after warming at 54 deg C.

Two possible solutions to this problem were investigated. The first is to warm the wing to above 54 deg C (for example, to 60 deg C), in this way achieving more time for the static test. The loads of the wing must reach the maximum level at the same time when the temperature decreases to 54 deg C. The second way is to try to thermally isolate the wing so that it cools down more slowly. These two solutions are examined in the experiments presented below.

Experiment number 2: Investigation of the cooling process of the wing structure after warming to 60 deg C

The set up of the experiment is similar that of Experiment 1. The recorded cooling process is displayed in Fig. 10. It is apparent that in case of the wing skin, the temperature cools down to 54 deg C in 100 sec. The spar flange reaches by this time the same temperature in 400 sec. Theoretically, having an efficient loading system, there is a chance to reach the maximum level of the wing loads within this time, but the temperature distribution will be unequal in the wing structure.

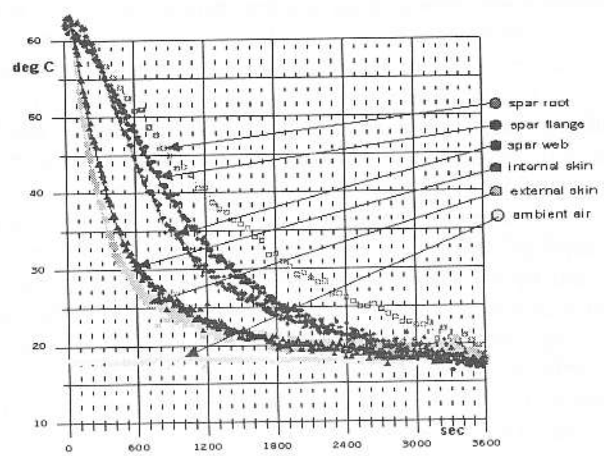

Figure 10. Cooling process of the PW-5 wing structure after heating in 62 deg C.

Experiment number 3: Investigation of the wing structure cooling process with a thermally isolated surface

The wing and a special sleeve made from an air bubble film were put into the heating chamber at a temperature of 54 deg C and warmed for 4 hours. The specimen was then inserted into the sleeve and kept at 54 deg C for the next two hours. After this, the wing with the sleeve was moved from the heating chamber to an ambient temperature of 20 deg C. The recorded results of the cooling process are shown in Fig. 11. As in the previous case, rapid cooling is visible. This time, however, this process is slower then in the case of the cooling of the wing without the sleeve. The doubling time (i.e. the time needed for reaching half of the effect of the cooling process) is approximately:

500 sec for the wing skin (previously 350 sec);

1100 sec for the spar flange (previously 900 sec);

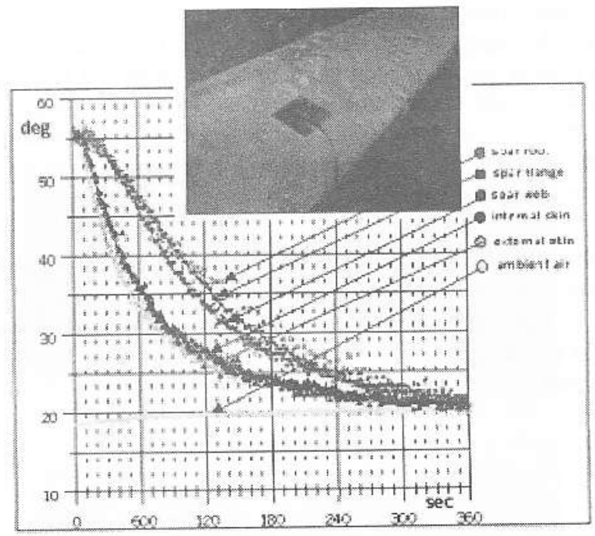

Figure 11. Cooling process of the PW-5 wing structure isolated by the air bubble film sleeve after heating at 54 deg C - diagrams of temperature.

The doubling times increase by about 50%. So, if we isolate the wing (insert into a thermal sleeve) in such a way that it does not interfere with the elements of the static test stand loading system, there is a chance to perform the strength test without the necessity of using a big heating chamber. The drawback of this method consists in the fact that the sleeve disturbs the observation of wing shell deformation during the static test.

The following conclusion can be drawn: all attempts to use a simplified method instead of the traditional method of static strength test at an elevated temperature result in serious problems with fulfilling the JAR-22.613 requirement. Therefore, it is worthwhile to know what methods are employed by the glider manufacturers for the certification tests of their gliders.

Experiment number 4: Investigation of the temperature change process in the wing structure of the glider parked under sunny sky

The objective of the experiment was to examine the warming process of the glider wing structure when parked under sunny sky, and compare the result to the temperature defined in the JAR-22 Regulations. The experiment was run in sunny day in June with the following weather conditions:

cloudiness small to medium, Cs 0 – 2/8; Cu 2/8 – 4/8;
average temperature of the air in the shadow – 23 deg C;
wind strength in the place of experiment: 0 – 3m/s;
humidity 60 – 65 %;

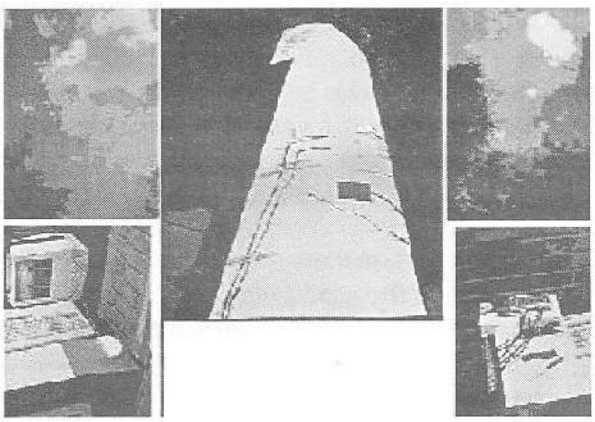

Figure 12. Investigation of the temperature change process in the wing structure of the glider parked under sunny sky.

The experiment started at 9:30 a.m., and ended 1:30 p.m. the same day. The recorded histories of temperature are displayed in Fig. 13. It can be seen that up to 10:00 a.m., the wing was in shadow. The temperature of the ambient air was about 19 deg C. At the moment the wing surface was exposed to the direct sun, a significant rise of temperature occurred.

The steepest rise in temperature was the part of the wing surface covered with a black paint (up to 55 deg C). As the sun exposure became more intense, the black surface temporarily reached the level of 67 deg C. The temperature oscillations are connected with the clouds blocking sun. The temperature of the external skin of the wing covered with a standard white paint reached the maximum value of 38 deg C. The internal skin in the periods of intensive sun activity was 2 to 3 deg C colder then the external skin. At the same time the spar flange was about 6 deg colder. Compared to the ambient air, the temperature of wing skin was approximately 15 deg C higher, and the temperature of spar flange was about 10 deg C higher. During the periods of large cloudiness, the temperatures of the different structural elements were similar., Nevertheless, the black painted part of the wing was noticeably warmer.

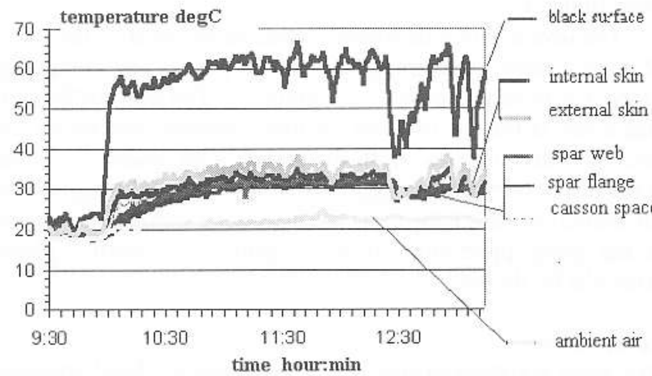

Figure 13. Diagrams of temperature measured in the wing structure during sunny day.

From the above, it follows that if the temperature of the air in shadow increases up to 40 deg C (which is quite possible in particular climates), the temperature of wing skin may reach the value of 54 deg C, which is the value defined by the JAR-22 Regulations. The conclusion is that the requirement imposed on the strength tests at elevated temperatures cannot be ignored.

Concerning the thermal protection of the glider structure, it is well known that the most effective one is that of white paint on the surface, as is shown in Ref. [3]. It is apparent that the most effective color is white, which has prevalence even over silver (like an aluminum foil). The difference of the temperatures between ambient air and the surface is 11 deg C for white color, and 47 deg C for black color.

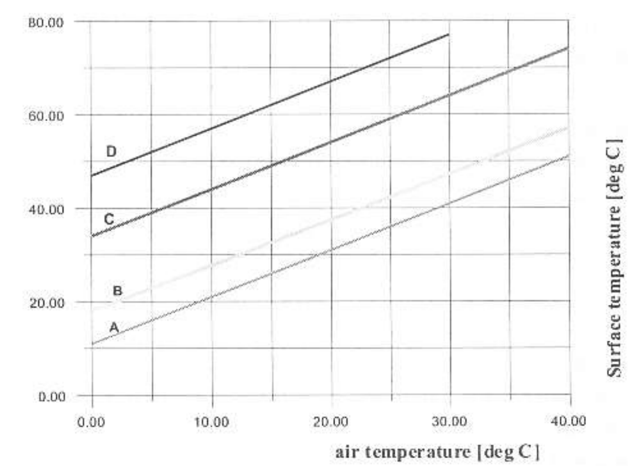

Figure 14. Color influence on the surface temperature of the GFRP covered with different paints, exposed to the sun.

A – white painted;

B – Aluminium foil on surface

C - unpainted composite;

D – black painted

Conclusions

The investigation described in this paper justifies the JAR-22 requirement concerning the strength tests of composite glider structures at elevated temperatures. The best method for such a test is the use of a big heating chamber, containing the loading system together with the glider being tested. As long as the technology of new resins with high thermal resistance is not introduced to glider industry, the white color is necessary as the main protection method against overheating glider structures by the sun.

References

[1] Joint Aviation Authorities Committee – *Joint Aviation Requirements JAR-22, Sailplanes and Powered Sailplanes*, Change 6, 1 August 2001

[2] MGS Marin G. Scheufler, Kunstharzprodukte GMBH – Technical Information 1998

[3] *Technika Lotnicza i Astronautyczna* 1973 nr 8.