THE EFFECT OF TECHNOLOGICAL DEFECTS ON PERFORMANCE OF FABRIC-REINFORCED COMPOSITES

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Abstract

The effect of manufacturing and service defects on glass-fibre composite components was studied. A methodology of repair of defects in such components dismantling parts from the structure is introduced using a novel vacuumless repair technology. Experimental characterisation of strength properties of standard samples, samples with defects and repaired samples under tension and compression was conducted.

1. Introduction

Modern textile composites combine high strength and stiffness and relative low density of carbon or glass fibres with ductility of a resin matrix. Due to high costs of such composites their main use was mostly limited to aerospace and defence structures and components (sports have been another important area). However, the current state is defined by a broad introduction of these materials into civil-engineering and automotive industries. Special ways to lay up thin (1/8 of a millimetre) plies of composites allows production of complex, large-scale structures, e.g. airplane wings. Exposed to in-service loads, they demonstrate initiation and evolution of damage. Hence, there is an urgent challenge of restoration of damaged component’s strength and load-bearing capacity in case of damage without replacement of the whole part. Besides, processes of manufacturing of these composite structures can also lead to defects and damage, even before the use of final products. Hence, the main focus of this work is to study these types of defects with regard to materials and structures used in aerospace applications. It includes a possibility of defects’ repair in sound-absorbing glass-fibre laminate panels and investigating the effect of manufacturing-induced defects in carbon-fibre specimens.

2. Repair technology

Structurally similar elements – samples of sound-absorbing panels (SAPs) were studied. They consist of perforated load-bearing skins and filler sandwiched between, which may be of tubular, cellular or honeycomb structure. Tubular specimens with dimensions of 150 mm × 350 mm (for tension test) and 150 mm × 450 mm (for compression test) were studied in this work. Filler as well as external skins were made of fiberglass employing traditional moulding. An artificially produced defect was placed in the central part of the sample to imitate an impact-caused rupture, which is characterized by damage of all reinforcing layers of the sample. The length of the defect was nearly half of the width of the specimen (see Fig. 1).

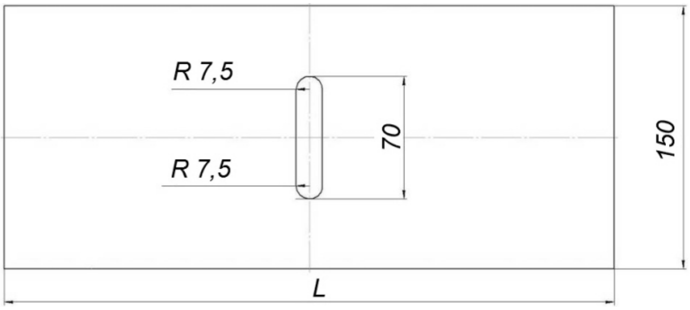

Figure 1. Draft of SAP sample with centred defect. *L*=350 mm – for tension tests, *L*=450 mm – for compression tests.

The principle of repair is in removal of the damaged layers and their replacement with reconstructing ones in compliance with direction of the original ones, as well as with adding two additional layers on top of the repaired spot on both sides of the sample. Schematically this procedure is presented in Fig. 2. Dimensions and orientation of the replacement layers correspond to those of the damaged layers.

The specialized equipment ACR3 Hot Bonder (Fig. 3) was used for the repair procedure. The main technical features of the equipment include the ability to repair structural parts without removing them from the structure (aircraft parts, for instance), which can significantly reduce costs and shorten repairs cycle. It also allows controlling the repair process in real time. Its operation principle is based on heating the repair zone with a flexible silicone heater with temperature control according to a predetermined program, with a possibility of stepwise temperature increases with a given speed and duration, with the simultaneous creation of a vacuum by means of an ejector and an electric pump.

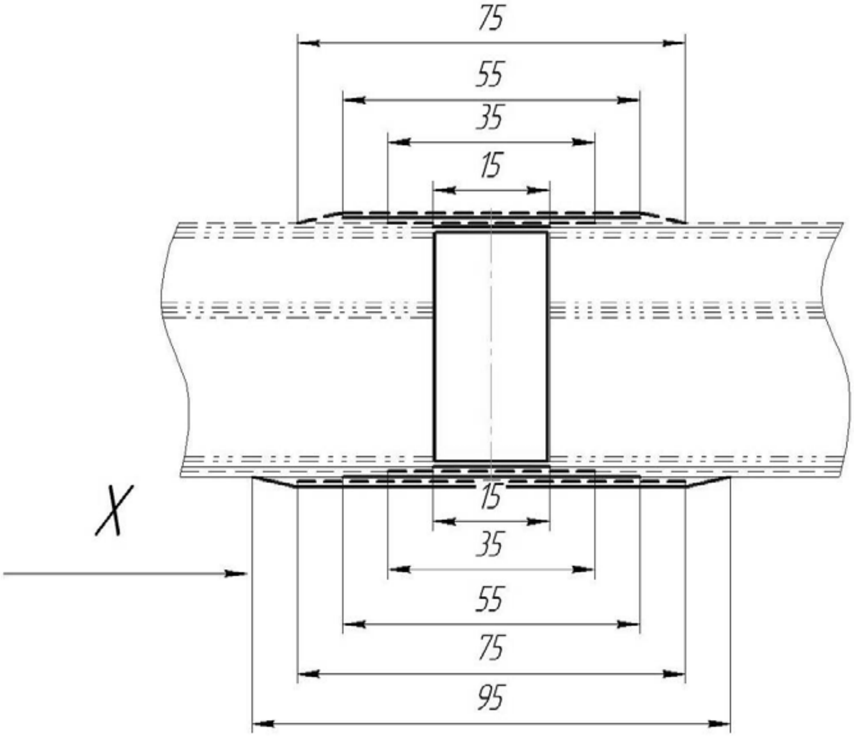

Figure 2. Repair scheme of through-tickness rupture of sample SAP
——— glass-fibre layer; orinetation along X axis;
- - - - - glass-fibre layer, orinetation is not regulated;
——— glass-fibre prepreg layer, orinetation along X axis;
— — — glass-fibre prepreg layer, orinetation across X axis;
— · · — glass-fibre prepreg layer, winding with 30-mm tape, the allowable overlap is no more than 3 mm, gaps are not allowed.

Figure 3. Hot Bonder kit

As the sample is perforated and repair zones are located on its both sides, the silicone heater was used without a vacuum. Moulding of the replacement layers was conducted by the contact method with a pressure of 0.1 kgf/cm^2. Hardening was performed at 60°C for 10 hours.

3. Experimental tests

For experimental studies, the standard SAP samples, samples with the defect and with the repaired defect (in each case – three for tension and compression each) were produced. Tests were conducted on a universal electromechanical testing system Instron 5882. The speed of elevating beam movement was 5 mm/min for tension tests and 2 mm/min for compression tests. The results of the experiments are presented in Tables 1 and 2.

	Maximal rupture load P_{max}, kN	**Elongation at rupture** U, **mm**
Tension of standard sample panels		
Sample 1	100.671	9.4
Sample 2	100.725	10.1
Sample 3	96.540	9.2
Tension of sample panels with defect		
Sample 1	39.461	8.3
Sample 2	53.117	7.5
Sample 3	62.151	10.3
Tension of repaired sample panels		
Sample 1	96.684	9.01
Sample 2	75.823	7.76
Sample 3	88.194	8.75

Table 1. Results of tension tests of SAP samples

	Maximal rupture load P_{max}, kN	**Elongation at rupture** U, **mm**
Compression of standard sample panels		
Sample 1	68.414	5.93
Sample 2	62.340	5.35
Sample 3	63.955	5.85
Compression of sample panels with defect		
Sample 1	33.072	3.0
Sample 2	31.179	2.6
Sample 3	41.843	3.6
Compression of repaired sample panels		
Sample 1	44.307	4.23
Sample 2	36.513	3.81
Sample 3	50.571	5.40

Table 2. Results of compression tests of SAP samples

Loading curves for the SAP samples in tensile and compression tests are shown, respectively, in Figs. 4 and 5.

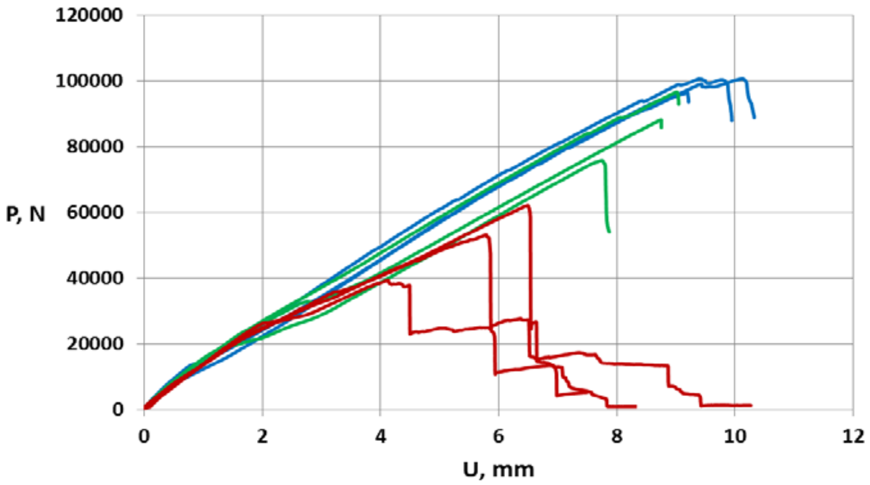

Figure 4. Loading curves for tension of SAP samples. Blue line – standard samples, red line – samples with defects, green line – repaired samples.

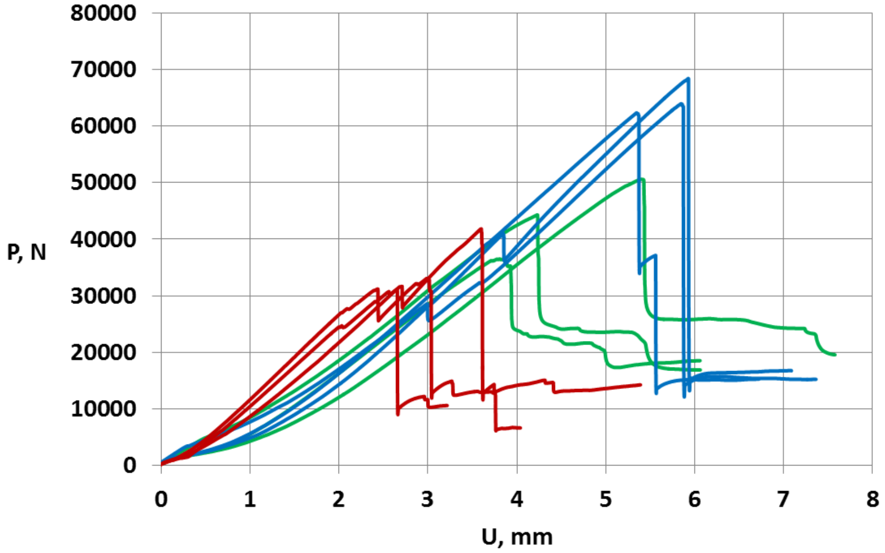

Figure 5. Loading curves for compression of SAP samples. Blue line – standard samples, red line – samples with defects, green line – repaired samples.

Upon reaching the limiting load, an instantaneously break of perforated load-bearing skins occurs followed by separation of their fragments without perforation and tubular filler. The difference in the values of the breaking load for different specimens can be explained by the inherent heterogeneity of the studied materials.

In the tension tests, two repaired SAP samples failed outside the repair zone, the third one – on the edge of this zone. This behaviour allows suggesting that the “healed” defect was not a stress concentrator.

In the compression tests, loading curves of two samples without defects have several drops, which can be explained by the local debonding of adhesive interface between the skins and the filler with subsequent local buckling of the skins.

In compression, all samples with repaired zone failed in the defect area, as the tubular filler was not restored and this area was the weakest section. Descending parts of the loading curves are explained by the process of structural damage, followed by buckling of skins and tubular filler over the entire length of the specimen panels.

4. Conclusions

A possibility of local repair of defects arising in service in typical elements of composite structures, such as sound-absorbing panels, has been considered. New vacuumless method of local repair of defects with reconstruction of damaged layers using modern specialized equipment was suggested. Experimental studies on the statistical residual strength of the SAP samples in tension and compression were performed. They showed that after the local repair of a defect area, compressive strength of the structure decreased by about 15-20% for all three samples. However, the tensile tests didn’t reveal a clear strength reduction in repaired SAP specimens. This fact confirms the possibility of exploitation of the repaired structures for some applications with dominant tension loading, but also demonstrates the necessity of further studies on improving the repair technology as well as on considering environmental factors.

Acknowledgements

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