ICAST2014 076

Measuring thermal diffusion in fiber metal laminates

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Abstract

The positive features of fiber metal laminates such as Glare lead to innovative applications. Positive features of Glare are e.g. a lower fatigue crack growing rate compared to monolithic Aluminum, better UV- and moisture-resistance compared to pure glass fiber laminates and good bearing strengths in combination with favorable impact and lightening resistance. Although, a lot of studies have been made, the thermal diffusion and temperature distribution at moderate temperatures of Glare have not been investigated in such detail. Therefore, this study investigated the temperature distributions of different Glare laminates during heating to moderate temperatures. The heating was realized by means of a local circular heat source at a horizontally positioned specimen. The temperature distributions at the top and bottom surfaces of the specimen were measured by means of thermo couples and at the top side by means of an infrared camera. The temperatures were evaluated at different positions and plotted as a function of time and after the initial heating phase. The test results showed that both, the thermo couples and the infrared camera measured similar temperatures at the top surface. Furthermore, the effect of the orthotropic material behavior of the prepreg layers was not visible in the in-plane-temperature distributions. The results showed as well, that a higher number of prepreg layers reduce the out-of-plane heat flux and thicker Aluminum layers cause higher temperatures at the bottom surfaces. Furthermore, it was concluded that the distance from the specimen center where the temperature of the top and bottom surfaces become similar are a function of the layup.

1. INTRODUCTION

The positive features of fiber metal laminates (FML) inspire designers to new innovative applications of fiber metal laminates such as Glare [8]. Glare (GLAss REinforced aluminum) is a fiber metal laminate which is composed of alternating layers of Aluminum and S-2 fiber glass prepregs [10]. Different Glare layups with different epoxy materials are certified in the aerospace industry. Thus, Glare is for example used for the fuselage and leading edges of an A380 [6].

Positive features of Glare are the lower fatigue crack growing rate compared to monolithic Aluminum [1, 12], the better UV- as well as moisture-resistance compared to pure glass fiber laminates [7] and good bearing strengths in combination with favorable impact and lightening resistance [9, 10, 11]. Those positive features make Glare suitable for damage tolerant parts [1].

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A large number of studies are concerned with the mechanical properties, the moisture content of the prepreg layers, the mechanical fatigue and impact behavior of Glare [4, 9, 10, 11]. However, few have been investigating the thermal properties of Glare as well as thermal cycling effects [2, 8]. Hagenbeek studied the thermal properties of the Aluminum layers and the prepreg layers separately [6]. Nevertheless, the thermal diffusion and temperature distribution at moderate temperatures of laminated Aluminum and prepreg layers, i.e. of Glare, is not investigated in such detail. Therefore, the goal of this research is to fill this gap and hence, investigate the temperature distributions in Glare laminates during heating to moderate temperatures. The temperature distribution as a function of time was investigated for different numbers of layers, Aluminum thicknesses and laminate layups.

2. Experimental procedure

The experimental procedure consisted in heating a plane Glare specimen in the center with a circular heat source and measure the temperature distributions at the top and bottom surfaces of the specimen (cf. Fig. 1, 2). For measuring the surface temperatures two independent systems were used. Thermo couples (TCs) were used for measuring the temperatures at the top and bottom surfaces of the specimens at several locations (cf. Fig. 2) and an infrared camera (IRC) was used to record the temperatures across the whole top surface (cf. Fig. 1).

2.1 Test setup

The test setup consists of a hot plate (heat source), an Aluminum cylinder for the heat transfer from the hot plate to the specimen and a wooden block to insulate the remaining part of the hot plate (cf. Fig. 1). The specimen is positioned horizontally. The center of the specimen is aligned with the axis of the cylinder (cf. Fig. 2). The cylinder is placed in a hole in the wooden block and has a diameter of 10 mm. The hole in the wooden block has the same diameter in order to minimize heat convection from the plate. Thus, the cylinder and the wooden block reduce the size of the heat source from the hot plate diameter 100 mm to the cylinder diameter 10 mm. In order to avoid heat conduction via the wooden plate to the specimen, the length of the cylinder exceeds the thickness of the wooden block by 3 mm. The thickness of the wooden block is 40 mm and provides sufficient insulation between the hot plate and the specimen. The length and width of the quadratic wooden block equal the dimensions of the specimens of 300 mm. Heat conduction paste is used in order to enhance the heat conduction between the hot plate and the cylinder as well as the cylinder and the specimen.

The tests are conducted according to the following procedure. At first, the hot plate is heated until the required temperature is reached. Secondly, the cylinder with the wooden block is placed at the top of the (pre-heated) hot plate. Finally, the specimen (cf. section 2.2) is placed at the hot plate and the temperatures at both surfaces as well as the ambient temperature are recorded.

2.2 Specimens

In this study Glare 3 and Glare 5 specimens were manufactured in a hand layup process in a clean room and cured with the standard procedure in an autoclave at temperatures of 120°C [6]. Glare 3 is composed of alternately laminated Aluminum layers (2024-T3) and two prepreg layers (S2 glass / FM 94) with the following layup [0° / 90°] [10]. Glare 5 consists of alternately laminated Aluminum layers and

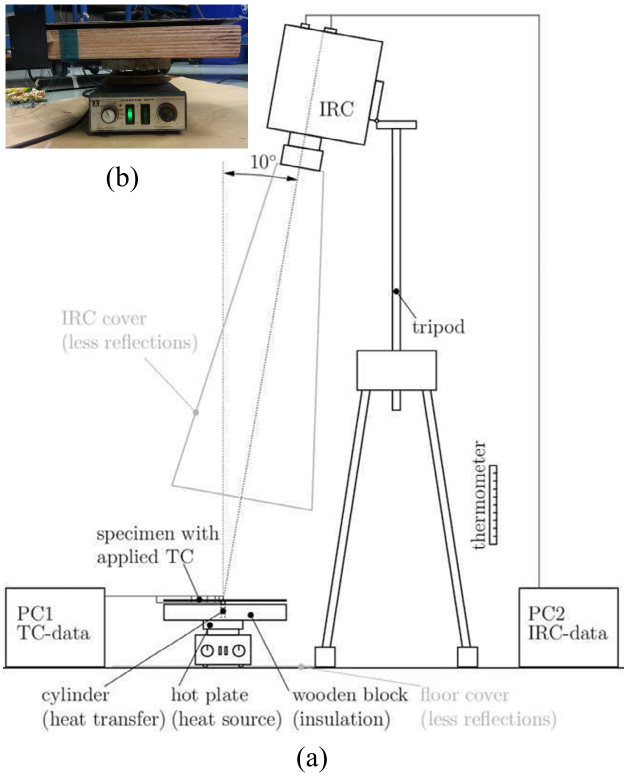


Figure 1. Test setup (a) overview and (b) detail

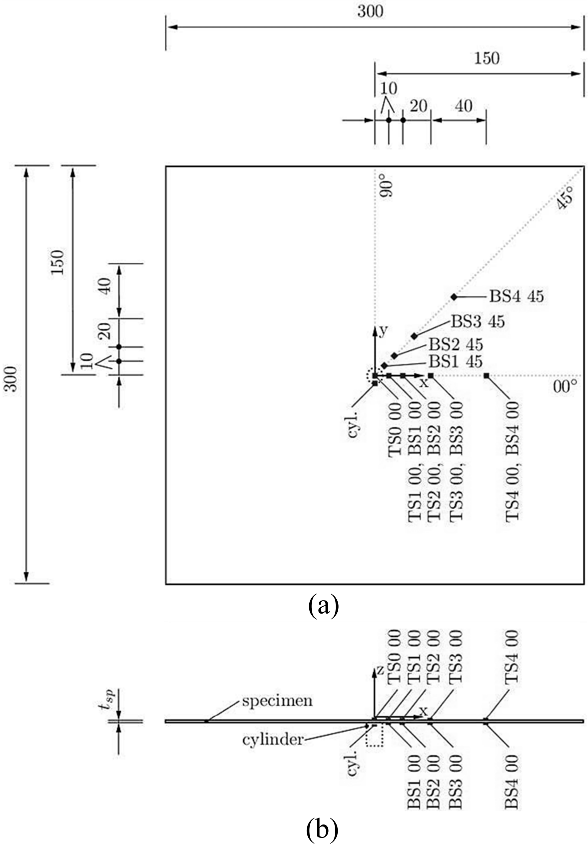


Figure 2. Specimen with applied thermo couples (a) plan view and (b) side view

prepreg layups with [0° / 90° / 90° / 0°]. For Glare 3 and Glare 5 both outer layers are Aluminum layers. The rolling direction of all Aluminum layers corresponds with the 0° direction of the pregregs. Each prepreg layer is an unidirectional lamina with a thickness of 0,133 mm.

Table 1 shows the investigated layups. Based on the reference specimen Glare 3-4/3-0,3 (REF) the number of layers, the thickness of the Aluminum layers and the number of the prepreg layers is varied. The size of the quadratic specimens results on the basis of preliminary tests which showed that dimensions of 300 mm are sufficient in order that the boundaries (edges) do not influence the area where the temperature is evaluated, i.e. within a radius of 100 mm (cf. Fig. 2).

Besides the application of the thermo couples, the specimens have to be painted (sprayed) with black matt paint before the testing can start. The matt black paint is necessary in order to reduce the possible reflections from the infrared camera itself and from the surroundings (cf. section 2.3). All specimens are inspected before the tests with a C-scan device. The C-scan results show no voids, no delaminations or other defects resulting from the manufacturing process.

2.3 Instrumentation

K-type thermo couples (TC) are used to measure the temperature at several positions at the top and bottom surfaces of the specimens (cf. Fig. 2). Towards the specimen center a smaller distance between the

Table 1 Glare laminates for specimens

nomenclature	Number of layers Aluminum (Al)	prepreg (pp)	Aluminum thickness [mm]	Glare laminate layup	prepreg layup (pp)
Glare 3-2/1-0,3	2	1	0,3	Al / pp / Al	[0° / 90°]
Glare 3-4/3-0,3 (REF)	4	3	0,3	Al / pp / Al / pp / Al / pp / Al	[0° / 90°]
Glare 3-6/5-0,3	6	5	0,3	Al / pp / Al / pp / Al / pp / Al / pp / Al	[0° / 90°]
Glare 3-4/3-0,4	4	3	0,4	Al / pp / Al / pp / Al / pp / Al	[0° / 90°]
Glare 5-4/3-0,3	4	3	0,3	Al / pp / Al / pp / Al / pp / Al	[0° / 90°/ 90°/ 0°]

thermo couples is chosen as the temperature gradient in the vicinity of the center is expected to be higher. The thermo couples on the top surface (TS) are positioned at the center of the specimen (TS0 00) and at distances of 10 mm (TS1 00), 20 mm (TS2 00), 40 mm (TS3 00) and 80 mm (TS4 00) from the specimen center along the x-axis of the specimens. The abbreviation 00 indicates the positions of thermo couples which are applied along the x-axis and correlate with the 0°-fiber direction of the prepregs. At the bottom surface (BS) thermo couples are applied along the x-axis and along the 45°-degree line x = y (cf. Fig. 2).

Consequently, the abbreviation 45 indicates the position of thermo couples which are applied along the 45°-degree line x = y. The positions of the thermo couples at the top and bottom surfaces along the x-axis are aligned. One further thermo couple is applied at the Aluminum cylinder close to the specimens. The thermo couple on the cylinder is used to record the temperatures with which the specimens are heated. The temperatures measured by means of the thermo couples are recorded with a sampling rate of 10 Hz.

A high thermal resolution infrared camera (FLIR Titanium Camera SC7300) is used to measure the temperature distribution across the top surfaces of the specimens [3]. The temperatures measured by the infrared camera (IRC) are recorded with a sampling rate of 5 Hz and a spatial resolution of 320 x 256 pixel. The camera is mounted on a tripod about 1500 mm above the ground. In order to reduce reflections from the surroundings and the camera itself, the camera is inclined by an angle of 10° (cf. Fig. 1). Furthermore, the floor is covered with a matt thick paper and a cover is mounted at the camera. The cover is made of cardboard and painted matt black inside. The purpose of the infrared camera is the two-dimensional temperature distribution across the top surface of the specimen, the disadvantage is that the temperatures at the bottom surface cannot be recorded.

The ambient temperature is recorded hourly with a digital and an analogue thermometer.

3. Test results

3.1 Reference layup

For the reference layup (Glare 3-4/3-0,3 REF) the surface temperatures of the bottom (BS) and top (TS) surfaces as well as at the cylinder surface are depicted as a function of time. Figure 3 shows the thermo couples temperatures at the bottom side along the x-axis, the 45°-line and the cylinder (cf. Fig. 2). Whereas Figure 4 depicts the thermo couple temperatures along the x-axis at the top and bottom surface as a function of the time. Table 2 shows absolute temperatures and temperature differences of selected

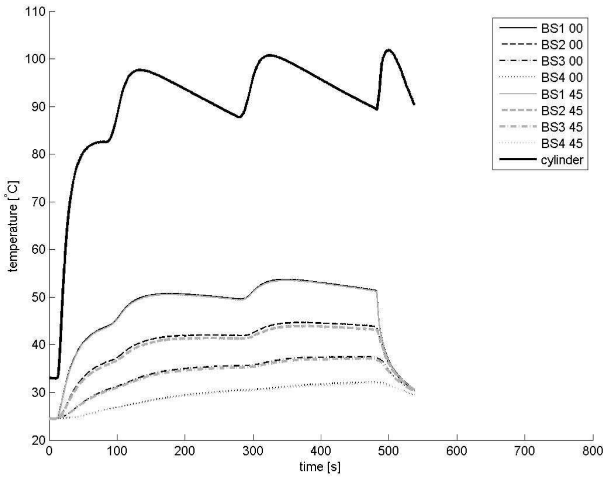


Figure 3. Temperatures of Glare 3-4/3-0,3 at the bottom surface and at the cylinder as a function of time recorded with thermo couples (cf. Fig. 2)

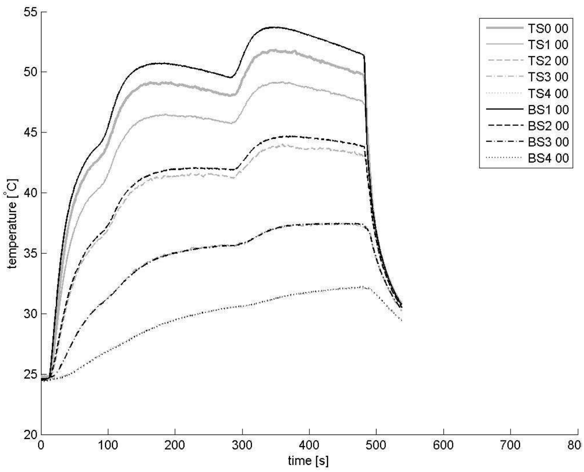


Figure 4. Temperatures of Glare 3-4/3-0,3 at the top and bottom surfaces as a function of time recorded with thermo couples (cf. Fig. 2)

thermo couples at time points during the steep temperature increase of the cylinder (heat source) at the beginning of the test and the thermo cycling phase. Furthermore, Table 2 shows the in-plane (col. 10-12) and the out-of-plane (col.13-14) temperature differences for the same time points.

Figures 3 and 4 show an initial heating phase followed by a thermo cycling phase which results from the controlling device of the hot plate. The temperature increase at the cylinder starts after 11 s. The cylinder temperatures increase steeply and flatten after 65 s where it stays at 82,4 ± 0,1°C until 85 s. Afterwards the thermo cycling phase starts where the cylinder temperatures range between 87,74°C and 100,7°C. The temperature decrease across the specimen after 480 s results from removing the specimen from the heat source and roughly reflects the cooling curve of the reference layup at an ambient temperature of 24,2°C. Furthermore, in Figure 3 the temperature changes of the hot plate (cylinder) can be noticed at the top and bottom surfaces as well. In the specimen center these temperature changes can be noticed most clearly (BS1 00, BS1 45).

According to the results presented in Figure 4 and Table 2, the (out-of-plane) temperature differences of the top and bottom surfaces are highest in the vicinity of the specimen center (BS1-TS1) and decrease towards the edges of the specimen (e.g. BS2-TS2). Furthermore, the temperature differences of the top and bottom surfaces at 10 mm distance from the specimen center (BS1-TS1) increase with increasing cylinder temperatures from 0 °C to 3,5°C during the initial heating phase, i.e. from 11 s to 65 s (cf. col. 13 of Table 2). After the initial heating phase the temperature differences BS1-TS1 level at 3,5 ± 0,1°C. During the thermo cycling phase BS1-TS1 increases to 4,4 ± 0,2°C at the local temperature maxima of the cylinder and decrease to 3,8 ± 0,1°C at the local temperature minima of the cylinder. Contrary to this, the temperature differences at a distance of 20 mm from the specimen center (BS2-TS2) from 0 s to 470 s constantly increase from 0 °C to 0,64°C (cf. col. 14 of Tab. 2). These small temperature differences of BS2-TS2 indicate that there are no significant temperature differences between the of the top and bottom surfaces for distances slightly larger than 20 mm from the specimen center. Thus, the out-of-plane temperature distribution can be expected to change from non-symmetric to symmetric in respect to the thickness of the specimen for distances larger than 20 mm from the specimen center.

When comparing the temperature differences, the results in Table 2 show that the in-plane-temperature differences TS0-TS1, TS1-TS2 and BS1-BS2 (col. 10-12) constantly increase during the heating phase and show local maxima and minima shortly after the cylinder temperatures reach local maxima and minima. This means, that the zone with a high temperature gradient moves from the cylinder center towards the specimen edges. However, with increasing distance from the specimen center, the effects of

Table 2 Temperatures at the cylinder (cyl.) and selected thermo couples at the top (TS) and bottom (BS) surfaces along the x-axis in °C at selected time steps for Glare 3-4/3-0,3 (REF) (cf. Fig. 2-4, 6)

	Temperatures in °C								Temperature differences in °C				
time in s	**cyl.**	**BS1 00**	**BS2 00**	**BS3 00**	**TS0 00**	**TS1 00**	**TS2 00**	**TS3 00**	**TS0-TS1**	**TS1-TS2**	**BS1-BS2**	**BS1-TS1**	**BS2-TS2**
11	32,97	24,64	24,57	24,61	24,79	24,74	24,77	24,67	0,05	-0,03	0,07	-0,1	-0,2
20	50,12	28,88	25,95	24,88	27,62	26,95	25,66	24,8	0,67	1,29	2,93	1,93	0,29
40	76,91	38,22	31,32	26,82	36,95	34,82	30,99	26,81	2,13	3,83	6,9	3,4	0,33
60	81,74	41,90	34,43	28,88	40,81	38,42	34,13	28,89	2,39	4,29	7,47	3,48	0,3
80	82,57	43,61	36,11	30,27	42,46	40,01	35,76	30,26	2,45	4,25	7,5	3,6	0,35
100	88,10	45,46	37,31	31,26	44,06	41,56	37,00	31,26	2,5	4,56	8,15	3,9	0,31
134	97,65	49,85	40,43	33,19	48,12	45,31	40,02	33,18	2,81	5,29	9,42	4,54	0,41
200	93,62	50,59	41,95	35,01	48,93	46,36	41,37	35,02	2,57	4,99	8,64	4,23	0,58
280	87,74	49,56	41,92	35,60	48,05	45,78	41,33	35,62	2,27	4,45	7,64	3,78	0,59
324	100,7	53,33	43,96	36,41	51,39	48,7	43,32	36,41	2,69	5,38	9,37	4,63	0,64
480	89,37	51,41	43,84	37,24	49,77	47,47	43,02	37,40	2,30	4,45	7,57	3,94	0,82

temperature variations of the cylinder decrease and the local maxima and minima flatten (Fig. 3 and 4).

Furthermore, Figure 3 shows that there is no significant temperature difference between the thermo couples at the bottom surface along the x-axis (BS1 00 to BS4 00) and the 45°-line (BS1 45 to BS4 45). The same results can be obtained by the temperatures recorded by means of the infrared camera at the top surface along the x-, y-axis and the 45°-line which can be seen in Figure 5.

The temperature distributions as well as the absolute temperatures recorded by means of the thermo couples and the infrared camera correlate (cf. Fig. 6). Both measuring systems show that at first the temperature increase of the heat source (cylinder) only affects a small area in the vicinity of the center which expands with further heating. Furthermore, both measuring devices record similar curves (shapes) for the temperature distributions which remain similar during the whole test. The top surface temperatures measured by means of thermo couples and the infrared camera differ less than 1,2°C, i.e. less than 2,5 %. The temperatures in the specimen center (TS0 00) differ most. The differences increase with increasing temperatures. This might result from the application of the thermo couple TS0 00 in the specimen center where the peak temperatures are expected (cf. Fig. 2). In addition to this, the thin layer of matt black paint might lead to slightly lower temperatures recorded by means of the infrared camera. As the specimen is painted after the application of the thermo couples, i.e. thermo couples are covered by the paint as well.

3.2 Further layups

The temperature distributions of all Glare layups from Table 1 are discussed after the initial heating phase, i.e. 65 s after the test start. Figure 7 a shows that for the first 70 s of the tests the heating curves (TC

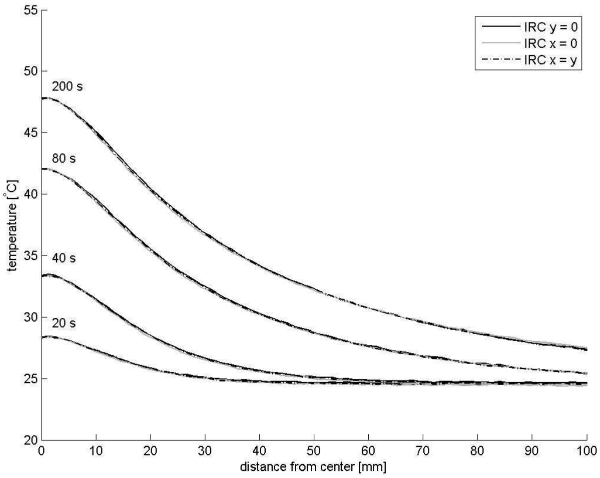


Figure 5. Temperature distribution at the top surface of Glare 3-4/3-0,3 along the x-axis (y = 0), y-axis (x = 0) and the 45°-line (x = y) at 20 s, 40 s, 80 s and 200 s recorded with the infrared camera

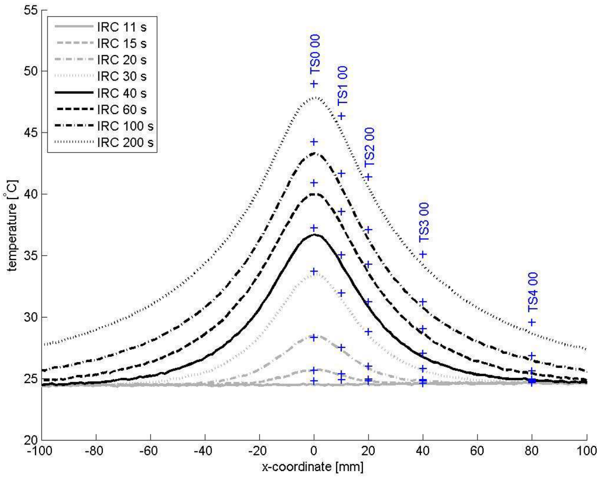


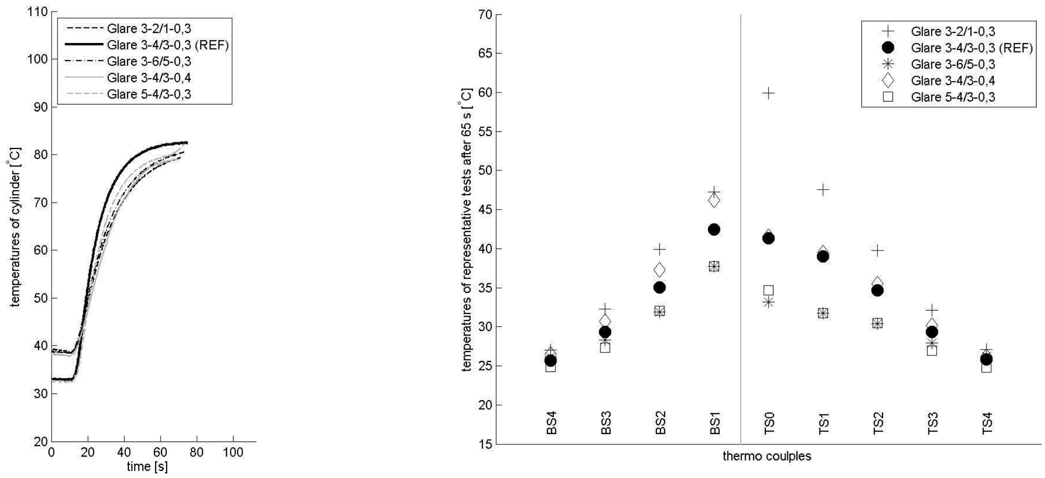
Figure 6. Temperature distribution at the top surface of Glare 3-4/3-0,3 along the x-axis (y = 0) for different time steps recorded with the infrared camera (lines) and thermo couples (+) (cf. Fig. 2)

cylinder) for all specimens are comparable. However, the interpretation of absolute temperatures has to be made sensitively in respect to the slight variations of the heating curves. The temperatures of the thermo couples applied at the bottom (BS) and top (TS) surfaces along the x-axis are depicted at the left and right side of Figure 7 b, respectively. Figure 8 shows the temperature differences of selected thermo couples in order to deduce correlations from the in- and out-of-plane temperature distributions. As all thermo couples are aligned along the x-axis the labelling is simplified. The ambient temperatures during all tests were 24 ± 0,6 °C.

In addition to the comments on the temperature distributions of the reference layup (Glare 3-4/3-0,3 REF) in section 3.1, some details 65 s after the start are pointed out. Figure 7 b shows that for the reference layup the maximum temperature occurs at bottom surface at 10 mm distance from the specimen center followed by the top surface temperature at the specimen center, i.e. BS1 > TS0. Consequently, the temperature at BS1 is larger than TS1 as well, i.e. BS1 > TS1. The temperature differences between the bottom and top surfaces decrease to values similar to zero at distances larger than 20 mm from the specimen center, i.e. BS2-TS2 = 0,37°C (see Fig. 8). Hence, the out-of-plane temperature differences for distances larger than 20 mm from the specimen center are about zero and a symmetric out-of-plane temperature distribution across the thickness can be expected.

Furthermore, Figure 7 b shows that the temperatures in Glare 3-2/1-0,3 in the vicinity of the specimen center are higher and decrease steeper with increasing distances from the specimen center compared to the reference layup. Contrary to the reference layup, the highest temperature in case of Glare 3-2/1-0,3 is measured at top surface in the specimen center, i.e. TS0 > BS1. Due to the steeper temperature decrease, the temperatures of the top and bottom surfaces start to level at smaller distances (10 mm) from the specimen center, i.e. BS1-TS1 = -0,28°C (see Fig. 8).

The temperatures and the temperature distributions in Glare 3-6/5-0,3 differ from the reference layup, but are similar to Glare 5-4/3-0,3 (cf. Fig. 7 b, 8). The surface temperatures of Glare 3-6/5-0,3 and Glare 5-4/3-0,3 compared to the reference layup are smaller at the top surfaces and slightly smaller at the bottom surfaces, i.e. TS0 < BS1. The in-plane temperature decreases in Glare 3-6/5-0,3 and Glare 5-4/3-0,3 are similar, but less steep compared to the reference specimen. The result of the smaller top surface temperatures in combination with the less steep in-plane temperature decrease in Glare 3-6/5-0,3 and Glare 5-4/3-0,3 are larger temperature differences between the top and bottom surfaces in the vicinity of



(a) (b)

Figure 7. Heating curves (a) and temperature distributions (b) for further layups at the top (TS0 to TS4) and bottom (BS1 to BS4) surfaces along the x-axis (y = 0) after 65 s (cf. Fig. 2,4)

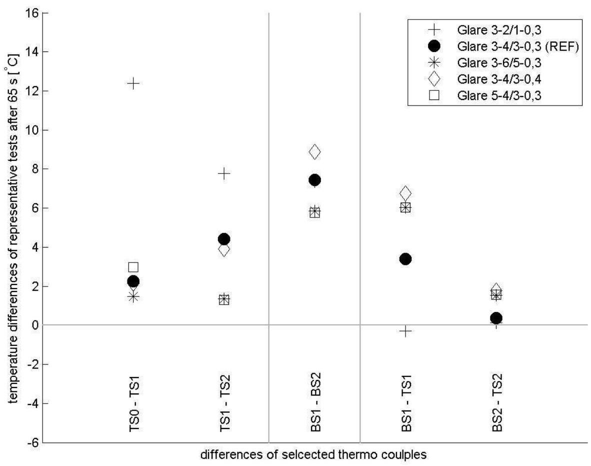


Figure 8. Temperature differences of selected thermo couples for further layups along the x-axis (y = 0) after 65 s (cf. Fig. 2,4,7)

the specimen center compared to the reference specimen, i.e. BS1 > TS1 and BS2 > TS2. Thus, the temperature differences between the top and bottom surfaces in Glare 3-6/5-0,3 and Glare 5-4/3-0,3 become about zero at distances between 20 mm and 40 mm from the specimen center.

Figures 7 b and 8 show that the bottom surface temperatures in Glare 3-4/3-0,4 are higher when compared to the reference layup. The top surface temperatures differ less, they are similar to slightly higher in Glare 3-4/3-0,4. Thus, the (out-of-plane) temperature differences of the top and bottom surfaces in Glare 3-4/3-0,4 become zero at larger distances from the specimen center than for the reference layup, i.e. BS1 > TS1 and BS2 > TS2. Compared to all other investigated layups, the temperature differences of the top and bottom surfaces are largest in Glare 3-4/3-0,4.

4. Discussion of results

The test results show an initial heating phase followed by a thermo cycling phase (cf. Figures 3 and 4). In the near future the test data will be used for numerical analyses with the aim to validate them and furthermore, to predict the temperatures of further layups when subjected to thermo (cyclic) loading. Despite the slight differences of the heating curves, some general statements can be made and trends detected.

The different in- and out-of-plane temperature distributions and temperature differences of the top and bottom surfaces in Figures 7 and 8 indicate different in- and out-of-plane heat fluxes in Glare laminates. The different in- and out-of-plane heat fluxes mainly result from the higher thermal conductivity coefficient of Aluminum (k = 122,2 W/m°C) compared to the prepreg layers, i.e. to an unidirectional laminate (k_1 = 0,74-0,95 W/m°C, k_2 = k_3 = 0,43-0,53 W/m°C) [6]. The indices 1, 2 and 3 indicate the assumed orthotropic material behavior of the unidirectional laminate. The index 1 corresponds to the fiber direction and the indices 2 and 3 to the directions perpendicular to the fibers. Furthermore, the Figures 3 and 5 show similar temperatures along the x-, y-axis and the 45°-line (x = y) at the bottom and top surfaces, respectively. This means that the far higher (isotropic) thermal conductivity coefficient of Aluminum levels out the different thermal conductivity differences with respect to the fiber orientation of the prepregs. Thus, similar in-plane heat fluxes regardless off the fiber orientation can be expected.

Figures 3 to 6 show that at first the center of the specimen heats up, then the temperature dissipates to distance further away from the center. The specimen center reacts more sensitive due to the smaller masses (smaller radii) in the vicinity of the heat source which have to be heated than to masses further away (larger radii) from the specimen center. Thus, the effect of the temperature variation of the heat source decreases and the delay of the temperature variation increases with increasing distance from the heated specimen center. However, due to the different masses, the in- and out-of-plane temperature decreases from the specimen center to the edges is steeper for thinner specimens (Glare 3-2/1-0,3) than for thicker specimens (Glare 3-6/5-0,3) (see Fig. 7). A higher number of prepreg layers (Glare 5-4/3/0,3) leads to less steep in-plane temperature decreases as well. This is due to the insulating effect of the prepreg layers with a lower thermal conductivity compared to Aluminum [6].

The results indicate that in case of an external heat source the most effective layup to reduce the out-of-plane heat flux consists of a high number of prepreg layers and thin Aluminum layers, e.g. Glare 5-4/3-0,3 (cf. Figure 7). As the prepreg layers act as insulation layers due to their lower thermal conductivity [6] and thus cause higher temperature decreases than Aluminum layers. Furthermore, it can be deduced that thicker Aluminum layers and to some extend a small number of prepreg layers increase the in-plane heat flux, e.g. Glare 3-4/3-0,4 (cf. Figure 7). As the higher thermal conductive Aluminum [6] transports more heat than a combination of Aluminum and prepreg layers of the same thickness.

Innovations, like the integration of embedded heater elements improve Glare to a smart material called heated Glare as proposed by the Fibre Metal Laminates Centre of Competence (FMLC) [4]. As the temperature distribution depends on the layup, an optimized layup could lead to a reduction of the electric power consumption during the heating periods. If it is required to melt the ice at the outer surface of leading edges by means of the embedded heater elements, then it might be an option to concentrate the heating power at the outer surface and to reduce heat fluxes towards the inside. Thus, it might be beneficial to put the embedded heater elements as close as possible to the outer surface and insulate the heater elements towards the inner side. These parameters indicate the use of Glare 5 where the embedded heater elements are positioned closest to the outer Aluminum layer, i.e. between the first and second prepreg layer when starting to count from the outer surface.

An effective layup design in order to realize high local temperatures at the outer surface close to the embedded heater elements, is to use a thin Aluminum layer at the outer surface. On the contrary, a thick Aluminum layer at the outside might be effective to distribute and store the heat from the embedded heating elements. However, one option to reduce the out-of-plane heat flux towards the inside surface further is to use thinner Aluminum layers towards the inner side of the leading edges.

5. Conclusions

The results of this study showed that when heating Glare laminates with a local external heat source in the specimen center to moderate temperatures, similar top surface temperatures are measured by means of thermo couples and an infrared camera. Furthermore, the temperatures of the top and bottom surfaces for Glare 3 showed that the effect of the orthotropic material behavior of the prepreg layers was not visible in the in-plane-temperature distributions. It can be assumed that the larger (isotropic) thermal conductivity coefficient of Aluminum levels out the orthotropic behavior of the prepreg layers.

The results showed as well, that prepreg layers act as an insulator and reduce the out-of-plane heat flux. As the temperatures differences of the top and bottom surfaces in Glare 5-4/3-0,3 (four prepreg layers between the Aluminum layers) are larger than in Glare 3-4/3-0,3 (two prepreg layers between the Aluminum layers). Furthermore, thicker Aluminum layers cause higher in-plane temperatures at the bottom surface.

The distance from the specimen center where the temperature of the top and bottom surfaces become similar is a function of the layup. As for a small number of layers the temperature decrease is steepest and flattens with an increasing number of layers. Thus, the distances where the temperatures at the top and bottom surfaces are similar are smallest for the specimens with a small number of layers (Glare 3-2/1-0,3) and increase with the number of layers (Glare 3-4/3-0,3 and Glare 3-6/5-0,3). Additional prepreg layers (Glare 5-4/3-0,3) reduce the temperature decrease in the vicinity of the specimen center as well and therefore increase the distance where the top and bottom surface temperatures are similar.

In a future step, the experimental data will be used to validate future numerical analyses. Those numerical analyses will be used to predict the thermal diffusion for more complex geometries, boundary conditions and applications when subjected to thermo (cyclic) loading.

ACKNOWLEDGMENTS

This study is funded by STW in cooperation with Fokker.

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