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Peel resistance of geopolymer sandwich with foam and honeycomb cores

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Abstract. Geopolymers are amorphous aluminosilicate materials which combine low temperature, polymer-like processing with high temperature stability and fire resistibility without toxic smoke generation. This work compares a conventional (glass/ phenolic resin) sandwich structure with a new sandwich structure (carbon/ geopolymer resin). In addition, three different manufacturing methods (hot bonding, cold bonding and curing/bonding in single operation) using four different adhesives were compared. Several types of organic and inorganic adhesives were used to bond the laminate skin to foam and honeycomb cores. The peel strength was two times higher than the reference glass/phenolic prepreg sandwich. In the group of honeycomb core specimens, the best results showed Resbond® 989 bonded specimens. The peel strength was three times higher than the reference sandwich. Fracture surfaces were evaluated considering the peel strength and load-displacement curves. This research can establish new fire resistible sandwich materials to be used in aerospace constructions.

Introduction

At present, there is an increasing need for materials eliminating fatal results of fire in case of aircraft accident [1]. A disadvantage of currently used composites is that they cannot be used in high temperatures, because their mechanical properties significantly degrade with increasing temperature [2]. Materials known as geopolymers have shown potential as a low-cost, environmentally friendly structural material with the ability to maintain strength at elevated temperatures [3]. Geopolymers withstands temperatures of over 1000 ºC and can be utilized as matrix in fibre reinforced composites. The main advantage of geopolymers is the excellent temperature stability; fire resistance with no generation of toxic fumes and smokes, low thermal conductivity and good specific strength [4,5]. Generally the sandwich structures are capable of absorbing large amounts of energy under impact loads with results in high structural crashworthiness [6] Combination of these properties predetermines geopolymer sandwich materials for use in aircraft structures. For larger expansion of geopolymer composites into the aircrafts constructions, it is necessary to know comparison of these materials with commonly used materials [7] and environmental impact (hot-wet/ cold conditioning, influence of the operating fluids, etc.) on mechanical properties [8].

This work compares a conventional (glass/ phenolic resin) sandwich structure with a new sandwich structure (carbon/ geopolymer resin). In addition, three different manufacturing methods (hot bonding, cold bonding and curing/bonding in single operation) using four different adhesives were compared.

Materials

To compare commonly used (glass/phenolic resin) and new geopolymer (carbon/geopolymer) sandwich panels, the effect of various cores and adhesives to the average peel strength was examined.

As the skin, three plies of carbon fabric Kordcarbon Industry (200 g/m^2, 3K, plain) in 0°/90° warp/weft orientation were used. The cores had thickness of 10 mm. Specimens had dimensions of 76 x 465 mm. In the group of foam core specimens, the best results were obtained for single operation sandwich bonding using uncured GPL 30 geopolymer resin that was manually impregnated with the carbon fabric and placed on the uncured foam core. Standard vacuum bag assembly was applied.

For the sandwich core, aramid honeycomb and thermoplastic polymer foam were used. Glass/phenolic prepreg (Gurit PHG 600-68-37 T2, style 7781) and carbon fabric (200 g/m^2 3K) manually impregnated with GPL 30 geopolymer resin was used for the skin of the sandwich. Geopolymer resin GPL 30 was fully developed in Czech Aerospace research Centre (VZLU). The components of the GPL 30 are shown in Table 1. The table also shows the weight and weight ratio of the individual components. In the first step, pure geopolymer resin was prepared (by mixing components 1-5) and then short ceramic and carbon fibres were added.

Table 1: Geopolymer resin composition

	Component	m (g)	wt. %
1	SiO_2 (Thermal silica)	513.24	35.24
2	$Al(OH)_3$	453.32	28.74
3	H_2O	158.48	10.05
4	NaOH	111.16	7.05
5	KOH	163.80	10.39
6	Ceramic fiber LYTX-311-L	84	5.33
7	Carbon chopped fiber Tenax® – A HT C124 3 mm	93.24	5.91
Σ		1577	100

Table 2: Test matrix

Set	Core	Adhesive	Skin	Manufacturing
REF	aramid honeycomb	none	glass/ phenolic resin	bonded in single operation
L30			carbon/ geopolymer GPL 30	
K84		Promat® K84		cold bonded
RESB		Resbond® 989		cold bonded
LFX		Letoxit® LFX 062		hot bonded
PH600		Gurit PHG 600-44-50 T2		hot bonded
REF	foam	none	glass/ phenolic resin	bonded in single operation
L30			carbon/ geopolymer GPL 30	
K84		Promat® K84		cold bonded
RESB		Resbond® 989		cold bonded
LFX		Letoxit® LFX 062		hot bonded
PH600		Gurit PHG 600-44-50 T2		hot bonded

Sandwich panels were made by three types of procedures. First - the skin was bonded with the core in single operation, second – precured skin was bonded by the adhesive by the cold bonding procedure, the matrix is shown in Table 2. Four types of adhesives were used.

Methods

Tests were performed on mechanical test machine Instron 55R1185 in accordance with ASTM D1781 - Standard Test Method for Climbing Drum Peel for Adhesives [9], at room temperature conditions. The average peel strength was determined using the integral method along 127 mm of the specimen length.

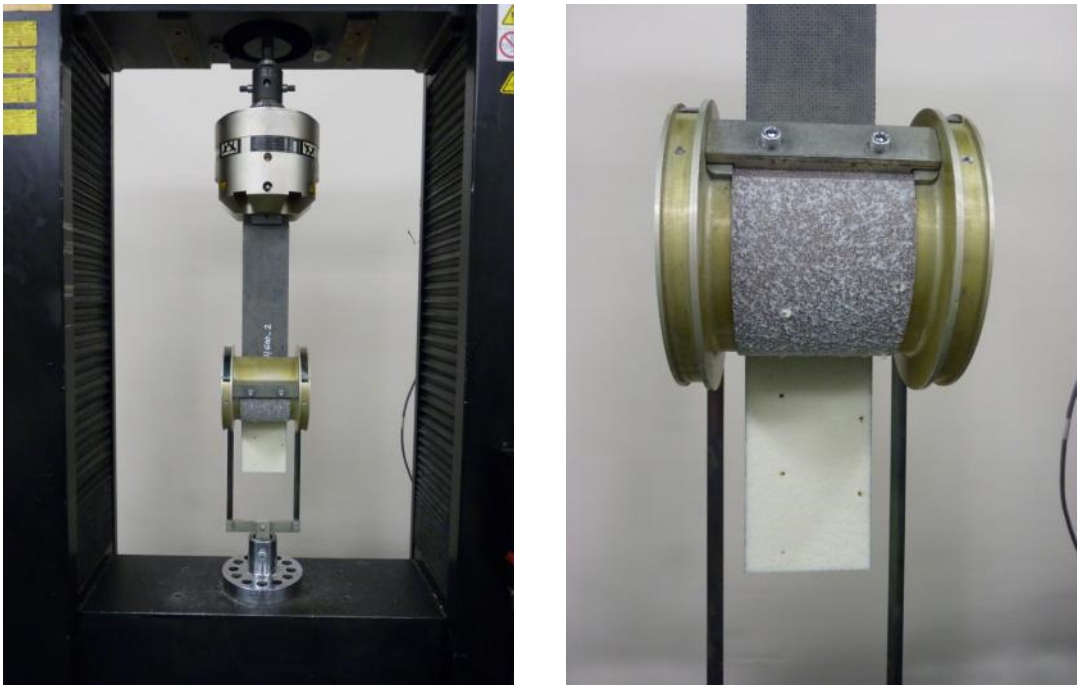

Figure 1: Test assembly of the drum peel test, overview and detail.

Results

Measured values of average peel strength and basic statistical evaluation (mean value, standard deviation – SD and coefficient of variation – CV) are shown in Table 3. All measured results were tested by Dixon's Q test on presence of outliers. Test was performed for significance level 0.05 and outlying values were not included into the test evaluation. A T-test was performed for determination whether the individual sets are significantly different from each other. Statistical significance 0.05 was chosen, Table 4.

Table 3: Measured average peel strengths in Nm/m, with statistical evaluation

	HONEYCOMB						FOAM					
	REF	*L30*	*K84*	*RESB*	*LFX*	*PH600*	*REF*	*L30*	*K84*	*RESB*	*LFX*	*PH600*
Mean	6.89	8.52	4.33	23.26	9.95	10.93	14.05	34.60	6.61	23.97	26.39	33.07
S.D.	1.60	1.14	0.21	2.07	2.44	1.18	0.19	7.96	0.32	1.24	2.31	1.04
C.V.	23.19	13.38	4.84	8.92	24.57	10.81	1.32	23.00	4.84	5.17	8.77	3.15

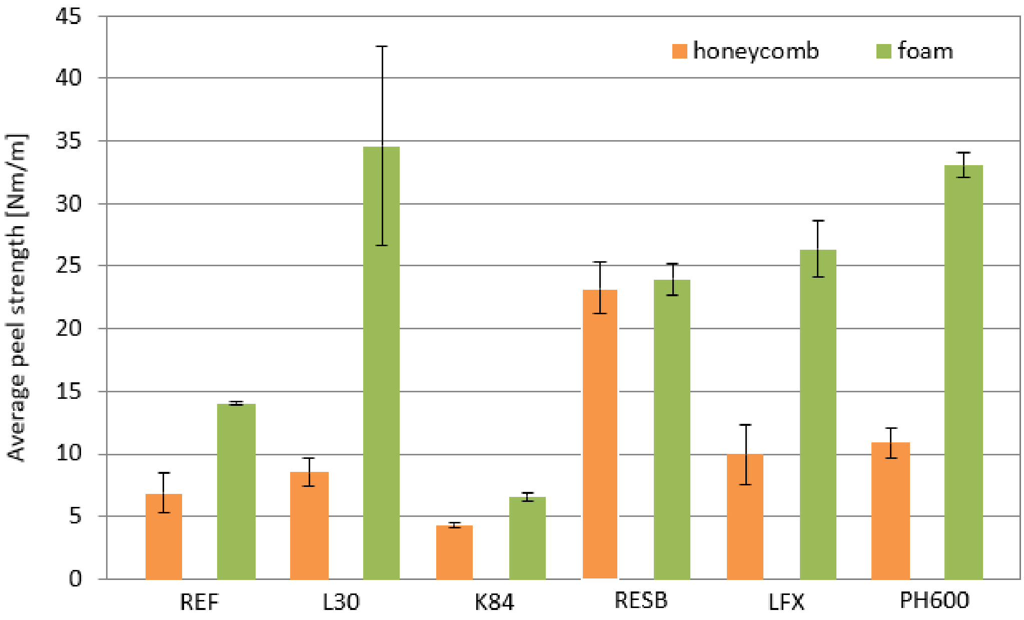

Figure 2: Measured average peel strengths in Nm/m.

In all cases, the average peel strength of foam sandwich samples was higher than the average peel strength measured on honeycomb samples. With exception of RESB series, the difference was evaluated as statistically significant. In the group of honeycomb core specimens, the best results showed set RESB (23.26 Nm/m) which was prepared by cold bonding. The peel strength was three times higher than the reference sandwich (6.89 Nm/m). In the group of foam core specimens, the best results showed set L30 (34.6 Nm/m), but on this set, the highest coefficient of variation (23 %) was also measured. Set PH 600 had the average peel strength less only of 4 % (33.07 Nm/m), but the CV was only 3.15%.

In comparison of REF and L30 sets (phenolic resin/ glass x geopolymer resin/ carbon), the measured values of average peel strengths showed that for honeycomb core was the difference statistically insignificant and for foam core was the difference statistically significant, see Table 4.

Table 4: Comparison of the results. ND: sets are not statistically significantly different, D: sets are statistically different.

	HONEYCOMB							FOAM					
	REF	*L30*	*K84*	*RESB*	*LFX*	*PH600*		*REF*	*L30*	*K84*	*RESB*	*LFX*	*PH600*
REF		ND	ND	D	ND	D	*REF*		D	D	D	D	D
L30	ND		D	D	ND	ND	*L30*	D		D	ND	ND	ND
K84	ND	D		D	D	D	*K84*	D	D		D	D	D
RESB	D	D	D		D	D	*RESB*	D	ND	D		ND	D
LFX	ND	ND	D	D		ND	*LFX*	D	ND	D	ND		D
PH600	D	ND	D	D	ND		*PH600*	D	ND	D	D	D	

Fractographical analysis was also performed. From each set was selected one referenced sample, macrophotography of the failure was made and compared with each other.

Figure 3 (comparing of honeycomb sets) shows a significant difference of the fracture surface between the set RESB and other sets. At RESB set, 75% of the adhesive remained on the core and 25 % on the skin. For other series the adhesive remained on mostly on skin. This is in agreement with the measured value of average peel strength, where the RESB series strength was 50 to 80% higher than for other series.

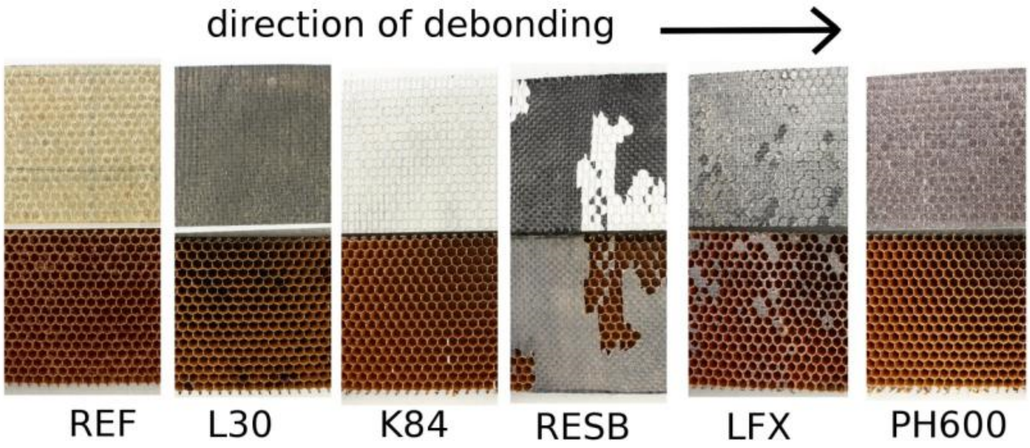

Figure 3: Fracture surfaces for honeycomb core specimens

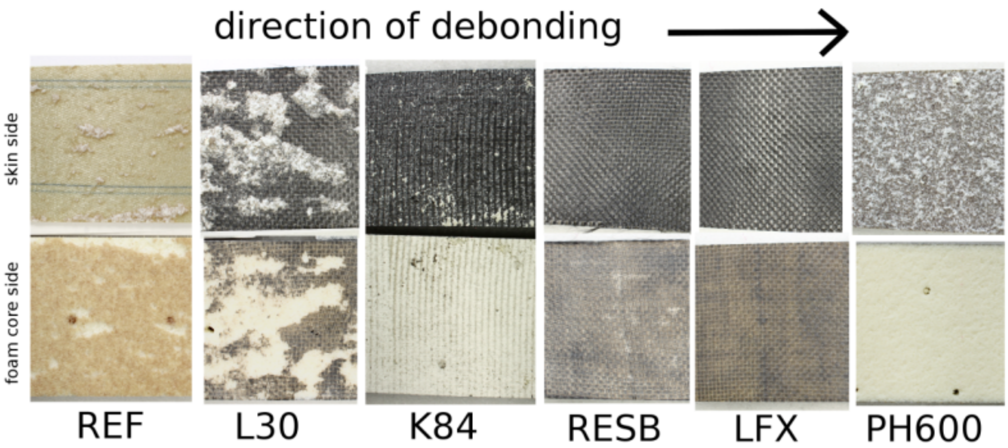

Figure 4: Fracture surfaces for foam core specimens

Figure 4 shows fracture surfaces for foam core specimens. When we compared the fracture surfaces with measured value of the peel strength, we can state that the major cohesive fracture in the core resulted in the highest peel strength (highest strength was measured on series RESB and PH600 where the cohesive failure dominated).

Conclusion

Highest strength values were measured on specimens with foam core and except the series where the Resbond 989 adhesive was used, the differences were statistically significant. From the honeycomb sets, the best results showed samples bonded by Resbond 989 - cold bonding. The peel strength was three times higher than the referenced set and one time higher than the second-best series PH600. In the group of foam core samples, the best results showed L30 series, but it is necessary to say that this set had big variation of the results (coefficient of variation was 23%). For second highest series was the average peel strength only 4% less and the variation of the results was approximately 3%.

Fractographic analysis of the fracture surface showed that for the honeycomb core has the strongest interface between the core and adhesive for the Resbond bonded samples and for foam core for the PH 600 series.

This paper showed that geocomposite sandwich panels can replace the commonly used sandwich panels.

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