CLIMATIC EXPOSURE EXPERIMENT OF STRUCTURAL ADHESIVES FOR HELICOPTER

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SUMMARY: The climatic exposure experiment of two moderate temperature curing structural adhesives at a hot, wet seacoast weathering site and a cold, dry weathering site are presented in this paper. The unloaded lap-shear joint and floating roller peel joint are employed to indicate the influence of different weathering and different joints. We can summarize that the hot, wet, seacoast weathering brought about deterioration at a far greater rate than the cold, dry weathering did, and the floating roller peel joint was more sensitive to hot, wet, seacoast site than the lap-shear joint was. The remaining strength of indoor lap-shear joint and accelerated aging experiment result were also discussed for comparison.

KEY WORDS: climatic exposure , structural adhesive, lap-shear, floating roller peel

INTRODUCTION

Adhesive metal bonding in aerospace applications often offers structural efficiency and manufacturing cost advantages over conventional, mechanically fastened structure. However, bonding technology is a polytechnic, adhesive bonding properties are influenced by a lot of factors which make bonding failure mechanism still unclear and long-term environmental durability of bonding structure lack of confidence[1]. In order to improve confidence in metal bonding in aerospace, it is very important to study the aging mechanism of adhesive. Usually accelerated testing techniques are employed , while different weathering outdoor exposure experiments are necessary for adhesives used in primary structures. Typical exposure site such as tropical seacoast and frigid weathering are preferred. In this paper, the outdoor exposure experiment of two 120°C-curing, rubber modified epoxy adhesive systems used for helicopter primary structures at two weathering site were studied, while accelerated test result was also presented to assess the effect of environmental exposure.

EXPERIMENTAL

Materials

Two 120°C-curing, modified epoxy adhesive systems A and B were chosen. Adhesive A includes film adhesive SY-24C and primer SY-D9, both are products of Beijing Institute of Aeronautical Materials. Adhesive B also includes a film adhesive and a primer, both are products of another company in P. R. China. The specification requirements of mechanical properties of adhesive A and B are identical.

Specimen preparing

2024-T3 alclad aluminum alloy was used to fabricate lap-shear and floating roller peel specimens. All specimens surface prior to bonding were treated by Chromic Acid Anodize. Specimens bonding process was finished according to process requirements of each adhesive system. All specimens surface were coated with anti-corrosion polyurethane coating after bonding to slow down the corrosion of aluminum during outdoor exposure.

Outdoor exposure

All specimens were placed in two main national atmosphere experiment base Wanning and Hailaer in September 20,1993.The main atmosphere data of two site are presented in Table 1.

Table 1: main atmosphere data of Wanning and Hailaer

		Wanning	Hailaer
Geographical site	North Latitude	18°58′	49°13′
	East Longitude	111°05′	120°06′
Height, m		12.3	687
distance to sea, km		0.2-0.3	>2000
year average temperature, °C		24.2	-2.5
Ultimate high temperature, °C		36.8	36.7
Ultimate low temperature, °C		6.8	-48.5
Ultimate temperature difference, °C		30.0	85.2
year average air pressure, millibar		1009.3	941.3
year average relate humidity, %		86	68
year average rain drop, mm		1515.0	339.8
year average sunshine time, hours		2026.5	2818.3
year average wind speed, m/s		2.9	3.5

Hailaer, Inner Mongolia, belongs to frigid climate, with large temperature difference, long sunshine time , heavy wind and very cold; Wanning, Hainan Province, belongs to tropical seacoast climate, usually very hot, humid and rich salt. Specimens at two site were exposed inclined 45degrees, with the major axis on the north-south line, facing to south and with

bondlines vertical.

Testing

All specimens were tested in Beijing after exposed for designed time per ASTM D1002 for lap-shear specimens and ISO4578 for floating roller peel specimens.

RESULTS AND DISCUSSIONS

Residual strength for lap-shear specimens

The residua lap-shear strengths of Adhesive A and Adhesive B after exposing outdoor at Wanning and Hailaer for 1, 2, 4 years were listed in Table 2, while the residual strength change with exposure time were shown directly in Fig. 1 and Fig. 2.

Table 2:Residual lap-shear strength change with exposure time, MPa

exposure time, year		A		B	
		Wanning	Hailaer	Wanning	Hailaer
0, strength		34.7/31.7-36.5		33.9/33.3-34.2	
1	strength	31.9/31.3-32.4	34.4/33.0-35.4	28.1/27.1-31.0	36.9/36.2-37.6
	retention	91.9%	99.9%	82.9%	109%
2	strength	28.6/27.5-30.1	38.8/37.3-39.9	27.3/25.6-28.5	35.5/34.8-35.9
	retention	82.4%	112%	80.5%	105%
4	strength	28.7/28.2-29.6	37.4/36.2-38.5	29.2/26.8-31.8	36.0/35.2-36.7
	retention	82.7%	109%	86.1%	106%

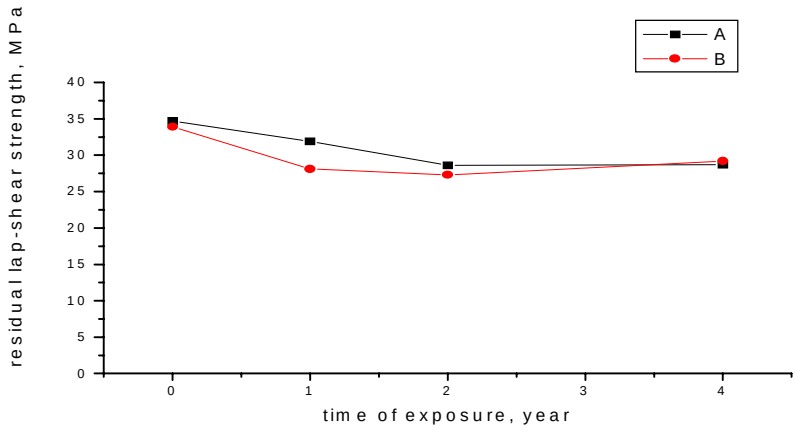

Fig. 1: Residual lap-shear strength of Adhesive A and Adhesive B in Wanning

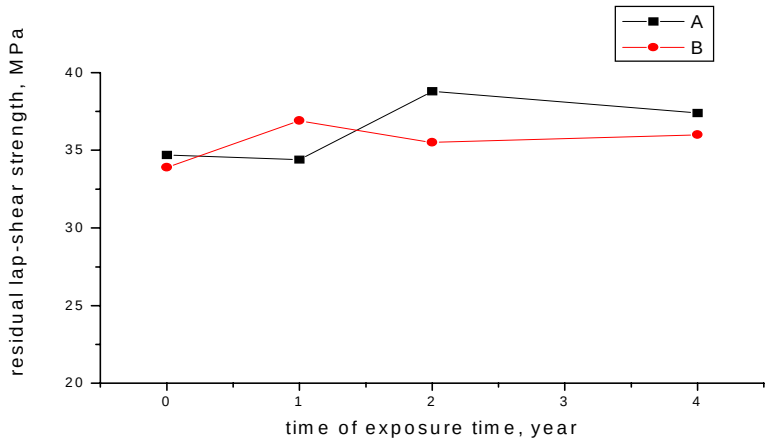

Fig. 2: Residual lap-shear strength of Adhesive A and Adhesive B in Hailaer

It is shown obviously in Fig.1 that residual strength of specimens in Wanning decrease quickly for both Adhesive A and Adhesive B, after 4 years exposure, the strength retention of A and B are almost the same. Fig. 2 shows that strength of specimens in Hailaer did not decrease for both Adhesive A and Adhesive B after 4 years exposure, which means that dry and cold atmosphere has little influence on lap-shear strength of Adhesive A and Adhesive B.

We can summarize from Fig. 1 and Fig. 2 ,strength decreasing rate of specimens in Wanning was much higher than that in Hailaer, indicated that the tropical sea-laden atmosphere did deteriorate both adhesives joints severely. Anyway, both Adhesive A and Adhesive B still retain their lap-shear strength more than 80% after 4 years exposure in Wanning.

Residual strength of floating roller peel specimens

The residual floating roller peel strengths of both Adhesive A and B, after exposed outdoor at Wanning and Hailaer for 1,2,4 years were presented in Table 3, the residual strength change with exposure time at two site were shown in Fig. 3 and Fig. 4.

Table 3: Residual floating roller peel strength change with exposure time, MPa

exposure time, year		A		B	
		Wanning	Hailaer	Wanning	Hailaer
0, strength		8.73/8.40-9.23		7.73/7.52-7.78	
1	strength	8.39/7.23-9.40	8.84/8.46-9.23	6.75/6.27-7.08	9.56/9.18-9.78
	retention	96.1%	101%	87.3%	124%
2	strength	5.59/4.86-6.75	8.95/8.54-9.59	5.76/4.58-6.74	9.76/9.64-9.92
	retention	64.0%	102%	74.5%	126%
4	strength	7.54/6.63-8.44	8.51/7.67-9.17	3.46/2.77-5.24	9.46/9.38-9.54
	retention	86.4%	97.5%	44.8%	122%

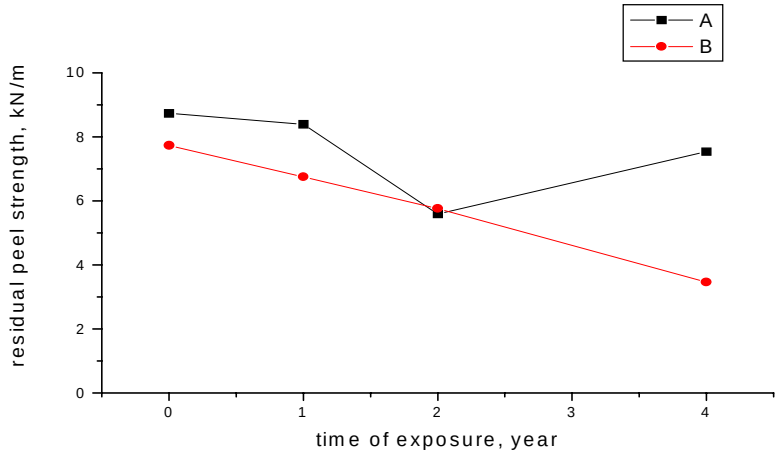

Fig. 3:Residual peel strength of Adhesive A and Adhesive B in Wanning

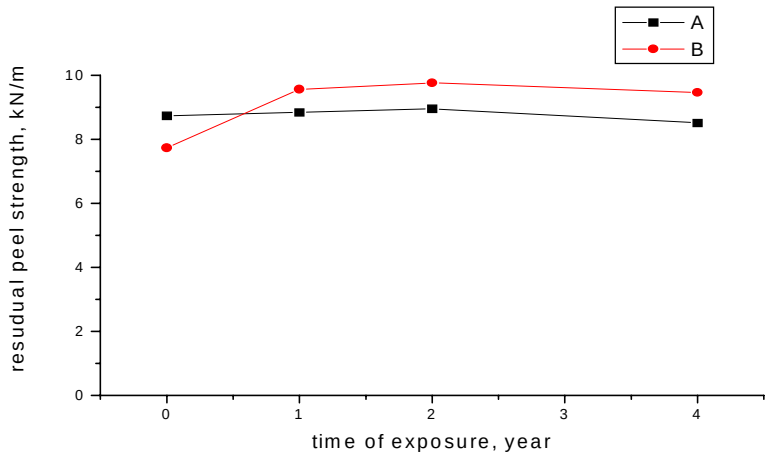

Fig. 4 : Residual peel strength of Adhesive A and Adhesive B in Hailaer

It could be seen clearly from Fig. 3, the floating roller peel strength for both Adhesive A and Adhesive B were largely influenced by tropical sea-laden atmosphere at Wanning. In 4 years exposure, strength decreasing rate of Adhesive B was much higher than that of Adhesive A. Fig. 4 shows that in Hailaer, strength of Adhesive A and Adhesive B did not decrease after 4 years exposure, just like the behavior of lap-shear joints did, also indicates that dry and cold atmosphere had little harm to floating roller peel strength of both Adhesive A and Adhesive B.

We can also summarize from Fig. 3 and Fig. 4 that floating roller peel strengths of specimens in Hailaer did not decrease, much higher than those in Wanning for both Adhesive A and Adhesive B, while the tropical sea-laden atmosphere did less deterioration to Adhesive A than to Adhesive B. In another word, the floating roller peel strength of Adhesive A was less susceptible to sea-laden atmosphere than that of Adhesive B.

Comparison between outdoor exposure and accelerated exposure

We can get a definite conclusion from above analysis that tropical sea-laden atmosphere at Wanning did more deterioration to both lap-shear joint and floating roller joint of both Adhesive A and Adhesive B than the cold and dry atmosphere at Hailaer did. Comparatively, floating roller joints were more sensitive to tropical sea-laden atmosphere than the lap-shear joints. For lap-shear joints in Wanning and both lap-shear joints and floating roller joints in Hailaer of Adhesive A and Adhesive B, the strength retention after 4 years exposure were almost the same, while for floating roller joints in Wanning after 4 years exposure, the strength retention of Adhesive A was 86.4%, much higher than that of Adhesive B, 44.8%, which means Adhesive A was less susceptible to the tropical sea-laden atmosphere at Wanning than Adhesive B.

In order to explain the difference performance between Adhesive A and Adhesive B at tropical sea-laden atmosphere, their accelerated exposure result and 4 years indoor store properties are listed in Table 4.

Table 4: Accelerated exposure result of Adhesive A and Adhesive B

lap- shear strength aging condition	test tempera-ture, °C	before exposure, MPa		after exposure, MPa		retention, %	
		A	B	A	B	A	B
hygrothermal aging[1]	R.T.	41.6	44.4	32.0	37.9	78.4	85.2
heat aging[2]	R.T.	38.8	42.7	38.0	43.2	97.9	101
hydraulic fluid[3]	70	34.7	24.6	33.3	19.9	96.0	81.0
hydrocarbon fluid[4]	70	34.7	24.6	34.6	23.6	99.7	96.1
loaded heat aging[5]	70	34.7	29.3	33.1	28.0	95.4	95.8
salt spray[6], Floating roller peel joint, kN/m	R.T.	9.1	11.0	8.8	6.9	96.7	62.7
	R.T.	corrosion area percent: 5.3% for A and 9.7% for B					
indoor store[7]	R.T.	34.7	33.9	36.2	38.7	104	114

1 aging at 70°C,95°C100%R.H. for 500 hours;
2 aging at 70°Cfor 500 hours;
3 90 days immersion in hydraulic fluid (MIL-H-83282) at 70°C;
4 90 days immersion in hydrocarbon fluid (70% Isooctane +30% toluene) at 40°C;
5 aging at 70°C under 5.6MPa stress for 1000 hours;
6 30 days salt spray exposure at 35°C;
7 4 years indoor store in Beijing.

It can be seen in Table 4 that hygrothermal aging strongly influenced Adhesive A′s lap-shear strength, while hygrothermal aging, hydraulic fluid immersion and salt spray strongly decreased Adhesive B′s properties. Although Adhesive B′s strength retention after hygrothermal aging was higher than that of Adhesive A, its corrosion area percentage after salt spray exposure was much higher than that of Adhesive A. Maybe that is the reason why Adhesive B′s floating roller peel strength retention was lower than that of Adhesive A after 4

years outdoor exposure at tropical sea-laden atmosphere in Wanning. The combination effect of heat , water and salt decreased Adhesive B′s strength sharply. Other accelerated exposure and 4 years store indoor in Beijing had little influence on both Adhesive A and Adhesive B.

Although a lot work has been done, the correlation between accelerated exposure and outdoor exposure is still uncertain, the experiment data is not enough to get a quantitative result. In order to explain the aging mechanism of Adhesive outdoor exposure more clearly, modern physical analysis method such as Scanning Electron Microscopy (SEM), X-ray Photoelectron Spectroscopy (XPS) etc. should be employed to analyze the failure mode and element distribution in the fracture surface of specimen after outdoor exposure at different weathering cite, then the diffusion rate of water vapor, salt spray and other corrosive vapor to adhesive layer and interface layer could be assessed, which can provide more data for assessing the life of a bonding joint.

Correlation between the experiment result and the life of bonding joint

Because there was no bondline edge protection in the specimens, they were actually at the worst circumstance during exposure. Actually bonding joints usually are used inner cabin of plane, the influence of heat, water vapor and other corrosion gas on bonding joints in actual service should be far less than that on outdoor exposure specimens, so the strength retention of in-service bonding assemblies should be higher than that of after outdoor exposure. We can conclude that , in any specific climate, the service life of bonding assemblies should exceed the years of outdoor exposure if the residual strength or strength retention is still satisfied to the design criteria after outdoor exposure.

CONCLUSION

Tropical sea-laden atmosphere in Wanning did more harm to bonding joints than frigid climate in Hailaer did, floating roller peel joints were more susceptible to tropical climate than lap-shear joints did. Adhesive A was more resistant to the sea-laden atmosphere in Wanning than Adhesive B possibly due to their different resistant to salt.

REFERENCES

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