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AN EVALUATION OF THE BORING WEDGE TEST FOR THE ASSESSMENT
OF CFRP SURFACE PRETREATMENT

by

B. M. Parker

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AN EVALUATION OF THE BOEING WEDGE TEST FOR THE ASSESSMENT
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SUMMARY

Boeing wedge specimens have been prepared from carbon fibre reinforced composites moulded against PTFE impregnated release cloth or silicone or PTFE release agents and pretreated by various abrasive methods.

The initial crack length has been found to be related to the surface coverage by contaminant and to the strength of lap joints prepared from similar composites. Crack growth on exposure to hot-humid conditions was not a function of surface contamination.



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1 INTRODUCTION

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The Boeing wedge test¹ was developed for the rapid assessment of the durability of adhesive bonded joints made from pretreated aluminium alloy adherends. Bonded lap joints of the same initial strength may have widely differing durabilities when exposed to hot-humid conditions. However it may take several weeks before differences in durability due to different surfaces become evident. The wedge test has been shown to provide information on durability in a few hours.

The specimen used for the wedge test is shown in Fig 1 with a wedge inserted. Adherends of equal thickness are bonded together. A stainless steel wedge with a line scribed between the shoulders is driven into the adhesive layer and the crack length, a , is measured between the scribed line and the end of the crack. Crack lengths are measured before and after exposure to a hot-humid atmosphere. Originally the test was designed for quality control of aluminium alloy pretreatments² and a pretreatment which resulted in crack growth greater than a specified length after exposure for a given time under given conditions was rejected as unsatisfactory. Subsequently the test has been used in various research and development applications, for example for the comparison of pretreatments for titanium³, and the comparison of high temperature adhesives⁴.

It has been shown⁵ that the strength of bonded single lap CFRP joints is dependent on the amount of contamination on the CFRP surface. This contamination is commonly due to the use of release agents in moulding of the CFRP adherends. While bonded lap joints discriminate between different degrees of contamination, the preparation and testing of joints is time-consuming and requires special jigs for controlling overlap lengths.

The aim of the present work is to assess the Boeing wedge test as a means of investigating the effect of surface contamination and of surface pretreatment on the properties of adhesive bonded CFRP joints. This Memorandum describes the effect of various levels of contamination on initial crack length and on crack growth during exposure to 50°C/96% RH. The results are compared with the strengths of corresponding single lap joints⁵.

2 EXPERIMENTAL

2.1 Composites

The carbon fibre reinforced composite used in this work was unidirectional Fibradux 914-CXAS with 10K fibre. 16 ply laminates, nominal thickness 2 mm, were moulded in an autoclave. The prepreg was cured against either a PTFE-coated release cloth or a metal plate coated with release agent which was either PTFE or a cured silicone. The resulting composite surfaces were those designated K1, L and M respectively in Ref 5.

2.2 Preparation of specimens

Composites were cut to the dimensions given in Fig 1. For metals the normal specimen length is 150 mm. Most of this work was done with 100 mm adherends as it was carried out on contaminated composite remaining from previous work⁵ which had required panels only 100 mm long. One uncut sheet of laminate moulded against release cloth was available. For this composite only, 150 mm adherends were used.

Composite surfaces were pretreated for bonding by one of the following:

- (a) Wiping free of dust with a tissue soaked in acetone. This is referred to as an untreated surface.
- (b) Hand abrasion with red Scotchbrite cloth.
- (c) Dry grit blasting with 240 grade white alumina grit using one or three passes of the gun.

(b) and (c) were followed immediately before bonding by an acetone wipe.

The pretreatments applied to each composite were carefully controlled in order to give approximately the same level of surface contamination as on these surfaces for which surface contamination and bonded joint strength data had already been obtained⁵.

Adherends of similar thickness were bonded together using Redux 312/5 modified epoxy adhesive. This was cured for half an hour at 120°C under sufficient pressure to cause resin flow. 20 mm was left unbonded at one end of each wedge specimen to allow the wedge to be inserted. The first batch of specimens to be prepared had a nominal glueline thickness of 0.1 mm (actual average 0.08 mm). It was found that with this glueline thickness it was difficult to insert a wedge without splitting the composite. Subsequent batches were therefore shimmed to give a nominal glueline thickness of 0.15 mm.

After bonding the excess adhesive was removed from the sides of the specimen. Several methods were tried. The best was found to be trimming the edges using a diamond slitting wheel followed by polishing with wet 400 grade silicon carbide paper. Care had to be taken to ensure that a flat surface was produced.

2.3 Wedge testing

Stainless steel wedges of the dimensions given in Fig 1 were driven in manually. The crack length (a) was measured using a travelling vernier microscope and was taken as the distance between the scribed line on the wedge and the end of the crack. Some initial cracks were measured within an hour of the wedge being inserted, others were measured on specimens which had been stored overnight in a desiccator after insertion. No difference in initial crack length or subsequent crack growth was found.

Specimens were then exposed to 50°C/96% RH. Crack lengths were measured after 1 hour of exposure and then at increasing time intervals until little or no more crack growth was observed.

Specimens were then broken open and the mode of failure examined. Failure in an adhesive-bonded composite joint can take place in the composite, at the interface between composite and adhesive or in the adhesive. Usually more than one mode of failure is present in any one joint.

3 RESULTS

Table 1 gives crack lengths measured initially and after two periods of exposure to 50°C/96% RH for the different combinations of initial laminate surface and surface pretreatment which were tested. The values of crack length at the longer exposure time are those measured after exposure for between 48 and 54 hours.

Also given in Table 1 are the percentage surface coverages by contaminants which were measured during the previous study of the effect of contaminants on lap joint strength⁵.

It is assumed that the surfaces bonded in this evaluation had the same levels of contamination, since all specimens were made from contaminated laminates remaining from the earlier work⁵ and surfaces were pretreated by the same methods.

On exposure to 50°C/96% RH, crack growth was observed (Table 1) only for adherends moulded against release cloth. Crack extensions for this composite with two surface pretreatments are shown as a function of exposure time (log (time) for convenience) in Fig 2.

Figs 3 to 5 show broken specimens for release cloth, silicone release agent and PTFE release agent contaminated surfaces respectively.

4 DISCUSSION

4.1 Composite moulded against release cloth

Specimens were prepared from composite which had been moulded against a PTFE-coated release cloth. The composite surface was either untreated (a) before bonding or was grit-blasted (c). The crack lengths measured initially and after two times of exposure to 50°C/96% RH are given in Table 1. Crack extensions are shown as a function of exposure time in Fig 2; the average and standard deviation on all five specimens is shown for the grit-blasted composite and individual results are shown for untreated composite. Difficulty was often experienced in determining accurately the position of the crack tip, particularly when the crack was along the composite-adhesive interface. It was not uncommon for there to be apparent decreases in crack length between individual consecutive measurements especially for specimens with grit-blasted adherends. However average crack lengths increased with exposure time.

Little or no growth was observed during the first 7 hours exposure for the specimens made with grit-blasted adherends but thereafter crack lengths increased until an approximately constant value was reached after 50 hours.

Initial crack lengths, crack growth and variability between specimens were much greater for specimens made from untreated composite. In contrast to grit-blasted specimens, most of the crack growth took place during the first hour of exposure. Two of the three specimens showed approximately constant crack lengths between 19 and 350 hours, while growth for the third specimen was slower and reached a maximum crack length after about 200 hours.

Initial crack lengths were clearly related to surface pretreatment of the adherend. Crack growth after 1 hour of exposure was also related to surface pretreatment as was crack growth at longer exposure times. Since little or no crack growth took place for grit-blasted composite specimens during the first few hours of exposure but did eventually occur, a better measure of resistance to crack extension might be obtained from measurements after 48 hours exposure.

Broken specimens from both sets are shown in Fig 3. Initial crack lengths are also given and the initial and final crack positions are indicated by arrows.

Specimens prepared with untreated composite failed initially partly at the interface between composite and adhesive and partly by removing some resin from the surface of the adherend. The crack grew by interfacial failure only and is visible as the slightly lighter band on the 'adhesive' side and slightly darker band on the 'composite' side of the joint.

Two grit-blasted composite specimens are also shown in Fig 3. These had different initial crack lengths. Again, initial and final crack positions are marked with arrows. The specimen with the shorter crack length failed during wedge insertion mainly in the adhesive with some failure in the composite while that with the longer initial crack failed mainly in the composite. The cracks appear in the figure as white bands near the centre of the length of each specimen. In both cases crack growth occurred in the adhesive rather than in the composite.

Thus for composites moulded against a PTFE impregnated release cloth, initial crack length, crack growth and mode of failure depended on the surface pretreatment given to the composite before bonding.

4.2 Composites moulded against release agents

Crack lengths before and after two times of exposure to 50°C/96% RH are given in Table 1 for several combinations of release agent and composite surface pretreatment.

From the data in Table 1 it can be seen that initial crack length depended on the surface pretreatment of the composite before bonding, although initial crack lengths tended to vary within each set.

Broken specimens are shown in Figs 4 and 5 for composites moulded against silicone and PTFE release agents respectively. Initial crack lengths are given for each specimen and the positions of the initial cracks are marked by arrows.

For the composite moulded against the silicone release agent, the specimen shown in Fig 4 which had received no pretreatment failed entirely at the interface between adhesive and composite; the initial crack ran the full length of the specimen. The surface on both faces of the specimen was smooth to the touch and it is probable that failure took place along the interface and that little or no bonding reaction had taken place between adherend and adhesive.

The specimen illustrating the effect of Scotchbrite pretreatment in Fig 4 was the only one of the set of four for which the initial crack did not run the full length of the specimen when the wedge was inserted. The crack stopped at the white line near the bottom of the specimen. Although it appears that failure was essentially the same as for the untreated specimen, the 'composite' surface shown in Fig 4 as the left-hand half of the specimen was appreciably less reflective than the corresponding half of the untreated composite specimen. It was also rougher to the touch inside the bonded area than outside, although pretreatment had been applied over the whole of the specimen

surface. This suggests that some bonding may have taken place between adhesive and adherend, although not enough to give any significant bond strength. Extensive surface analysis would be required to determine the precise location of failure.

The specimens of composite moulded against silicone and dry grit-blasted had initial crack lengths of the same order as for grit blasted 'release cloth' surfaces. A typical failed specimen is shown in Fig 4. Failure during wedge insertion was partly in the adhesive and partly in the composite and was similar to that shown in Fig 3 for a specimen of similar initial crack length. The final position of the crack, as shown by the arrow, was near the centre of the specimen. When the specimen was split open after exposure, failure took place almost entirely in the composite.

Only two pretreatments were investigated for composite moulded against a PTFE release agent, namely one and three passes of the grit blast gun. Typical broken specimens are shown in Fig 5, the positions of the cracks being indicated by arrows. Both specimens failed during wedge insertion mainly in the composite with a small area of interfacial failure down each edge and with the position of the failure relative to the composite surface varying across the specimen width. This effect was probably caused by uneven surface pretreatment. Initial crack lengths depended on the extent of pretreatment.

Thus, for both mould release agents, initial crack lengths and modes of failure depended on surface pretreatment. However, in contrast to the 'release cloth' composites, there was no crack growth observed during exposure to 50°C/96% RH (Table 1). The reason for this difference is not understood but may be related to differences in surface roughness or contaminant distribution⁵.

4.3 Correlation of initial crack length with surface contamination and joint strength

The data presented in Table 1 show that initial crack length depended on the source of contamination and on surface pretreatment. Fig 6 shows that there is no general relationship between initial crack length and level of contamination, but this is not surprising as the data shown were obtained for different sources of contamination which probably resulted in differences in both the distribution and nature of the contamination. However, for each source of contamination the initial crack length increased as the concentration of contaminant increased (Table 1, Fig 6). The values of surface concentration of contaminant shown in Table 1 were determined during earlier work by XPS of small samples of composites⁵. It is possible that these measurements do not accurately reflect the *mean* concentrations of contaminants on the laminate surfaces used to prepare either the single overlap joints⁵ or the wedge specimens. However, it is interesting to note that a consistent relationship between initial crack length and lap shear strength⁵ was obtained (Fig 7) when data for the same sources of contamination and similar surface treatments were compared. Further work appears to be required to establish the precise relationship between initial crack length and surface concentration of contaminant, for a range of contaminants and adhesives.

5 CONCLUSIONS

Boeing wedge tests with adhesive bonded CFRP adherends showed that the length of the initial crack depended on the nature and the extent of contamination of the CFRP adherend surfaces. Contamination resulted from curing laminates against PTFE coated release cloth or metal plates coated with PTFE or silicone release agent. In each case grit-blasting with dry alumina grit prior to bonding resulted in shorter initial crack lengths, in agreement with the lower levels of contamination and higher joint strengths reported previously⁵.

When cracked specimens were exposed to 50°C/96% RH no significant crack growth was observed for specimens made from laminates cured against coated metal plates. However, in the case of specimens made from laminates cured against release cloth, cracks grew during exposure. For untreated laminates, total crack growth was between 5 and 7 mm and most growth took place during the first hour. For grit-blasted composite growth was less than 2 mm. In both cases more or less constant crack lengths had been reached after 48-50 hours exposure.

Initial crack length measurements with CFRP Boeing wedge specimens can provide a rapid and simple means of detecting surface contamination on adherends. However the variability of results was high and small differences in crack length were equivalent to significant differences in bonded joint strength. The Boeing wedge test may not therefore be sensitive enough to discriminate between acceptable and unacceptable levels of contamination on bonding surfaces, and other test methods may be preferred.

It is evident that further work is required to establish whether the Boeing wedge test is a useful method of investigating contamination on CFRP surfaces and to establish the most suitable and sensitive method of measuring the effect of surface contamination on the performance of bonded CFRP joints.

Table 1

**CRACK LENGTHS FOR CFRP BOEING WEDGE TEST SPECIMENS
BEFORE AND AFTER EXPOSURE TO 50°C/96% RH**

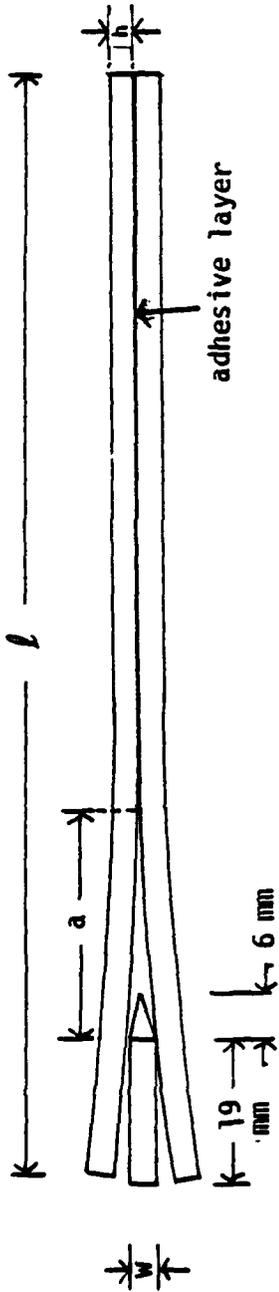
| Source of contamination | Surface pretreatment | Approximate surface contamination (atomic %) ⁵ | Crack length (mm) after exposure | | | |
|-------------------------------|-------------------------------|---|----------------------------------|---|---|--|
| | | | Initial | 1 hour | 48-54 hours | |
| Release cloth | None | 20 | 61.0 | 64.1 | 65.6 | |
| | | | 60.4 | 65.9 | 67.3 | |
| | | | 46.5 | 49.7 | 51.5 | |
| | Dry grit blast (three passes) | 4 | 39.2 | 39.1 | 40.5 | |
| | | | 36.5 | 37.2 | 37.8 | |
| | | | 38.3 | 38.8 | 39.6 | |
| | | | 33.9 | 36.5 | 39.8 | |
| | | | 44.7 | 44.7 | 46.1 | |
| | Silicone release agent | None | 77 | >81.5 | crack ran full length of specimen when wedge inserted | |
| | | | | >81.5 | | |
| >81.5 | | | | | | |
| Scotchbrite | | 60 | 71.4 | 70.9 | 70.0 (a) | |
| | | | >82.5 | crack ran full length of specimen when wedge inserted | | |
| | | | >82.5 | | | |
| Dry grit blast (three passes) | | 24 | 34.6 | 34.5 | 34.2 | |
| | | | 37.4 | 37.1 | 37.8 | |
| | | | 31.6 | 32.1 | 30.4 | |
| PTFE release agent | Dry grit blast (one pass) | 61 | 51.9 | 51.7 | 50.7 | |
| | | | 46.2 | not available | | |
| | | | 41.4 | 42.0 | 41.2 | |
| | Dry grit blast (three passes) | 29 | 40.3 | 40.6 | 40.0 | |
| | | | 44.7 | 44.6 | 44.4 | |
| | | | 37.6 | 36.9 | 37.4 | |
| | | | | | | |

(a) Value interpolated between results at 24 and 72 hours

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| | Metal | CFRP |
|--------------------|---------|---------------|
| wedge thickness | 3.25 mm | 2.1 mm |
| adherent thickness | 25 mm | 25 mm |
| adherent width | 150 mm | 100 or 150 mm |
| adherent length | | as measured |
| crack length | | |

Fig 1 Boeing wedge test specimens

Fig 2

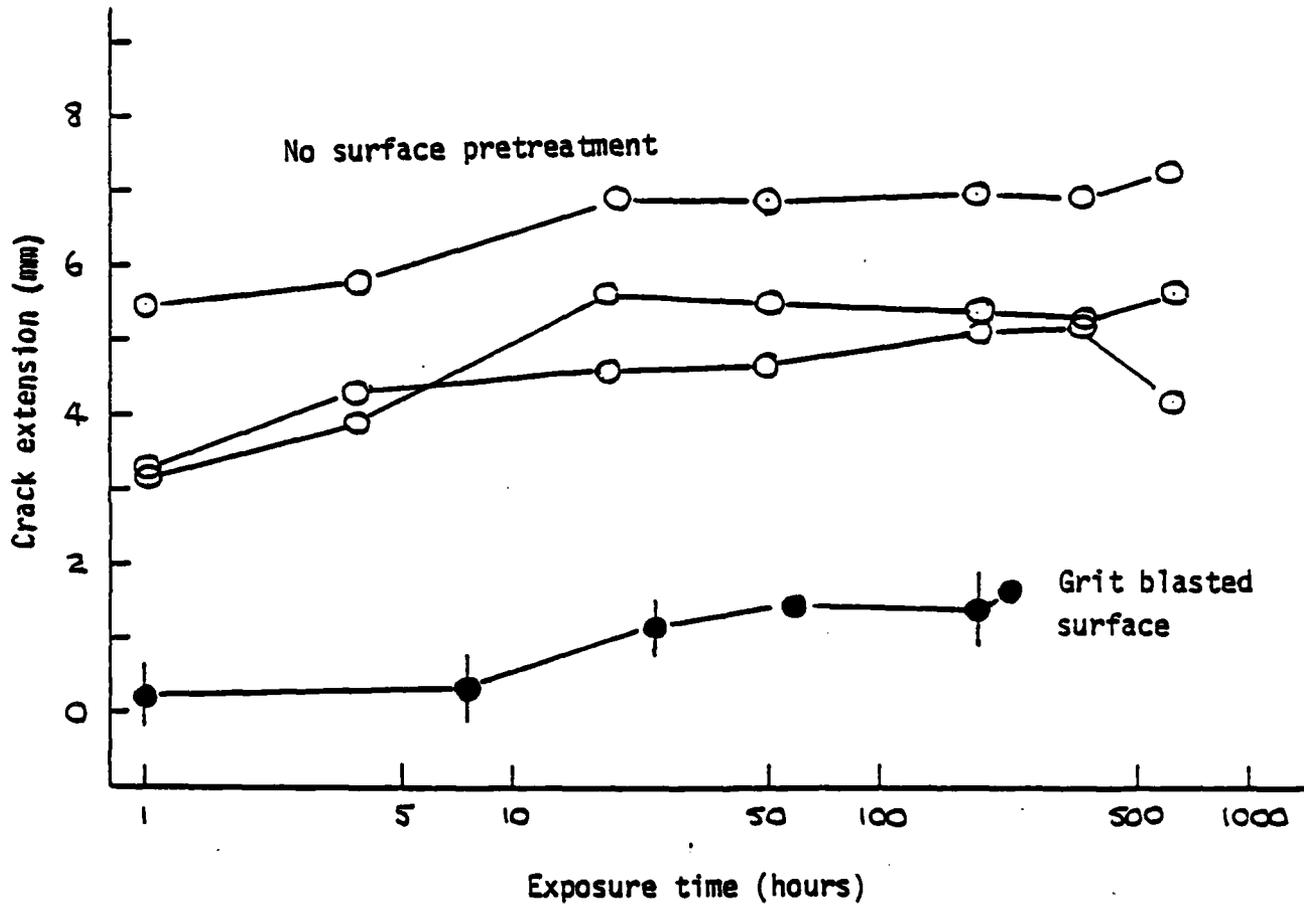
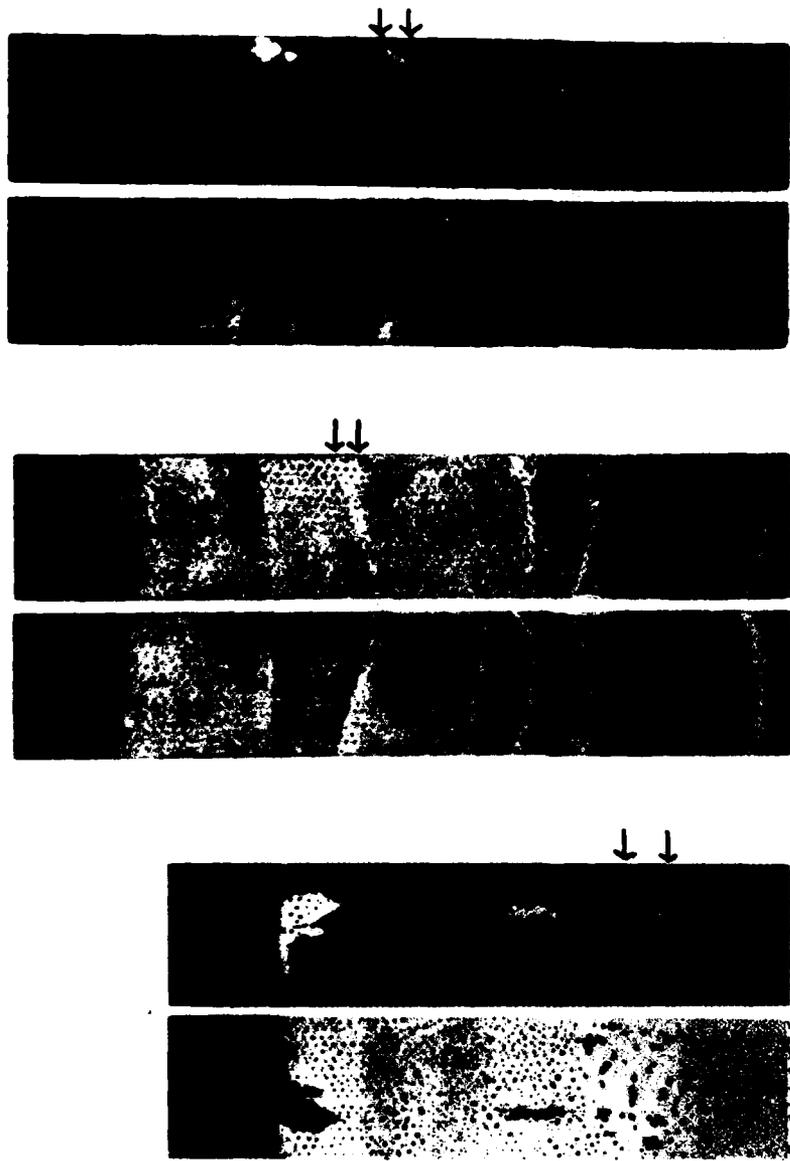


Fig 2 Crack extension to 50°C/96% RH for Boeing wedge test specimens of CFRP moulded against release cloth and bonded with Redux 312/5 adhesive



Pretreatment
Initial crack length

None
55.6 mm

Dry grit blast x 3
33.9 mm 44.7 mm

Fig 3

Fig 3 Broken wedge specimens prepared from composite moulded against release cloth

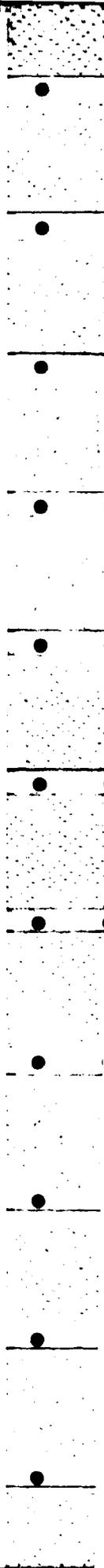
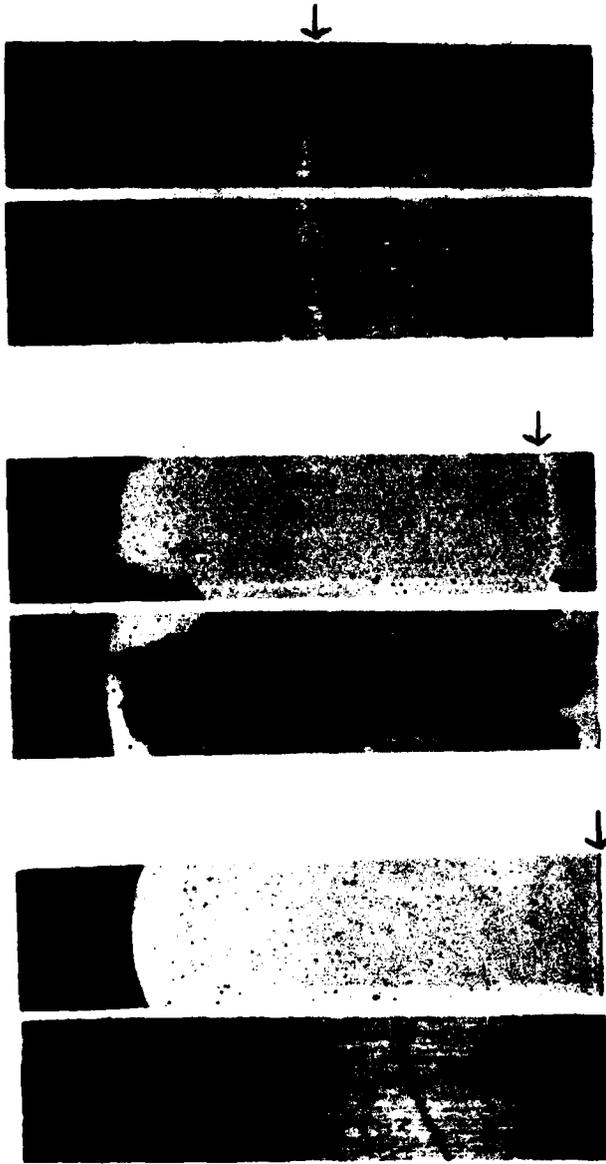


Fig 4



Pretreatment
Initial crack length

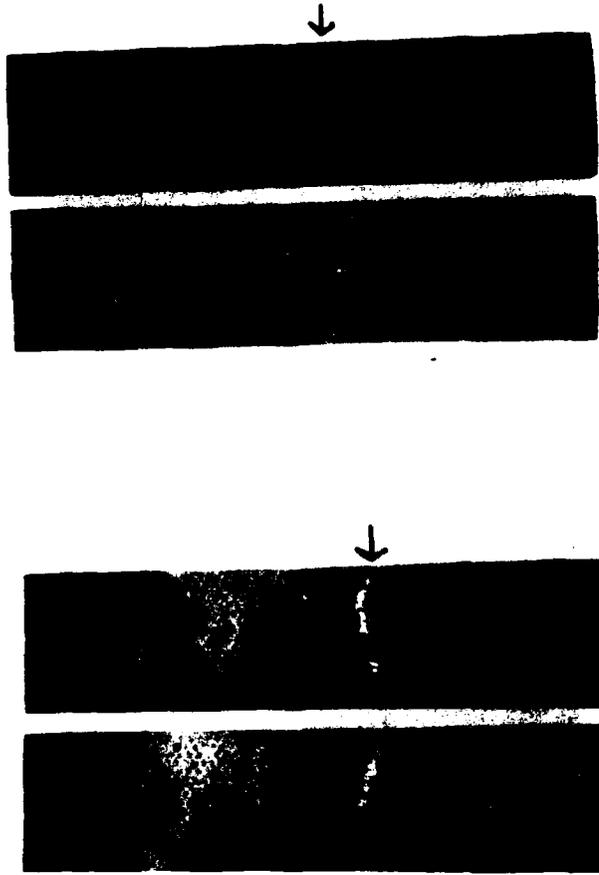
None
Full length

Scotchbrite
71.4 mm

Dry grit blast x 3
31.6 mm

Fig 4 Broken wedge specimens for composite moulded against a silicone release agent





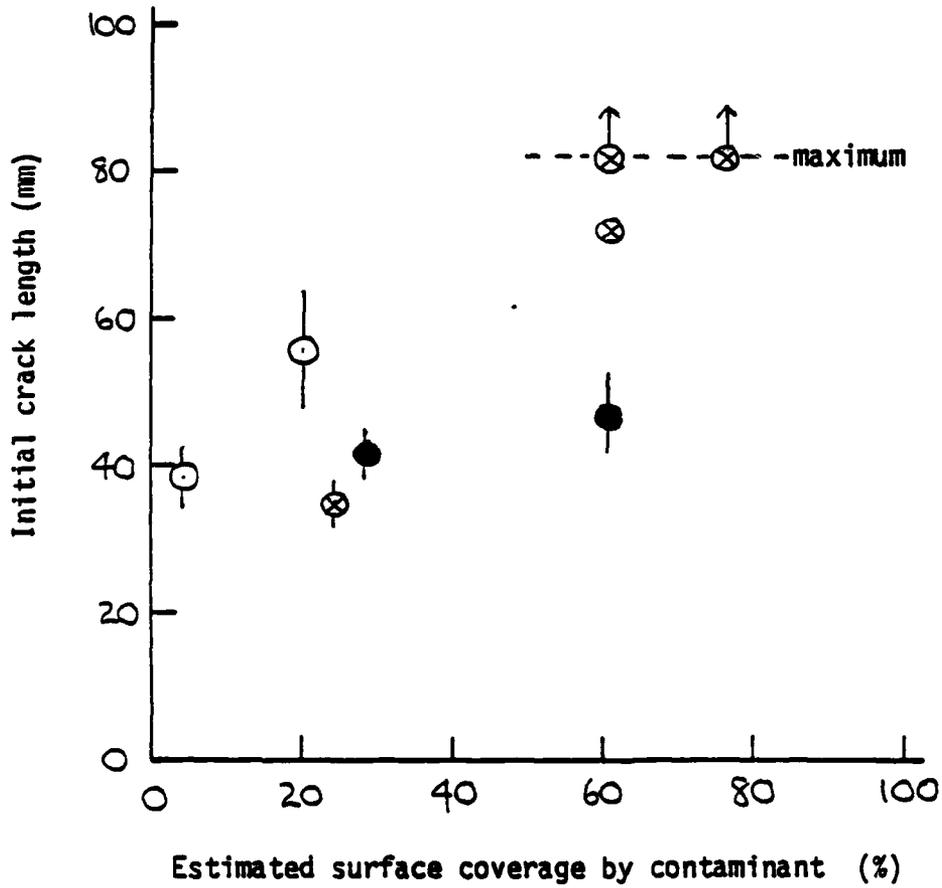
Pretreatment
Initial crack length

Dry grit blast x 1
41.4 mm

Dry grit blast x 3
37.6 mm

Fig 5 Broken wedge specimens for composite moulded against a PTFE release agent

Fig 6



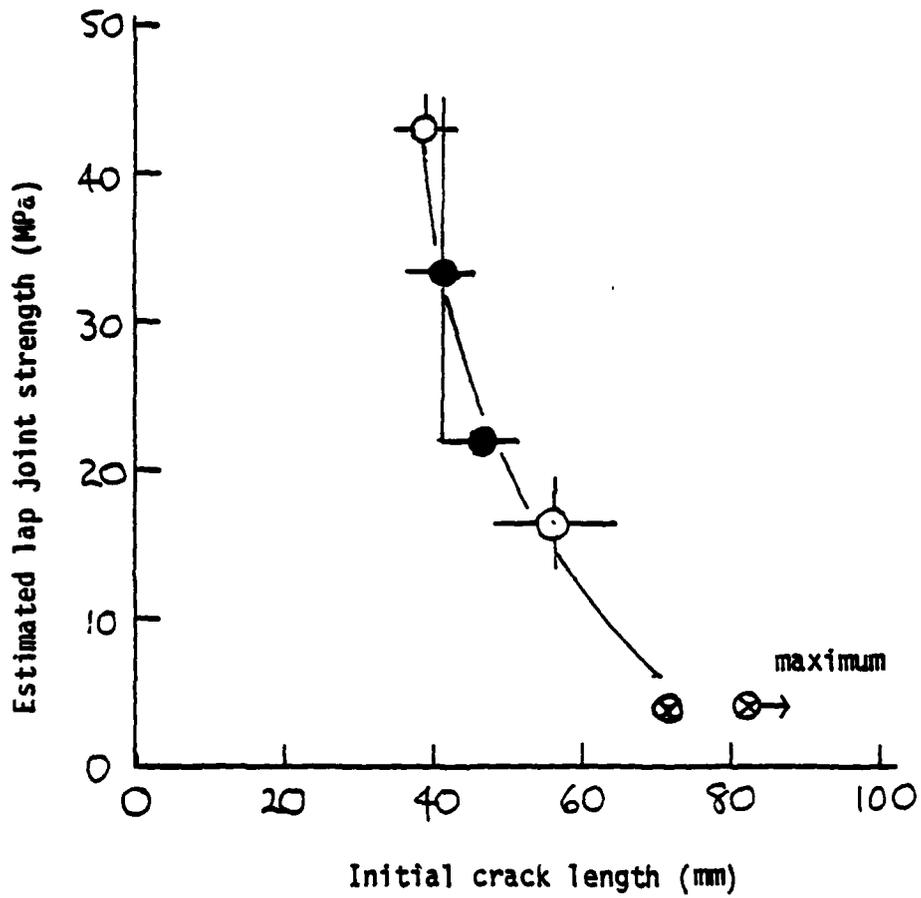
Surface

- Release cloth ○
- Silicone release agent ⊗
- PTFE release agent ●

Fig 6 Relationship between contaminant coverage of adherent surface and initial crack length for Boeing wedge joints bonded with Redux 312/5

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Fig 7



Release cloth ○
Silicone release agent ⊗
PTFE release agent ●

Fig 7 Relationship between initial crack length and lap joint strength for contaminated CFRP bonded with Redux 312/5 adhesive

REPORT DOCUMENTATION PAGE

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| 17. Abstract Boeing wedge specimens have been prepared from carbon fibre reinforced composites moulded against PTFE impregnated release cloth or silicone or PTFE release agents and pretreated by various abrasive methods. The initial crack length has been found to be related to the surface coverage by contaminant and to the strength of lap joints prepared from similar composites. Crack growth on exposure to hot-humid conditions was not a function of surface contamination. (POLYTETRAFLUOROETHYLENE) | | | | | |

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