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A Study of How Stitch Placement Affects the Open Hole Tension Strength of Stitched Textile Composite Materials

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Abstract

This paper investigates the relationship between open hole tensile strength and distance between a hole and a stitch in a textile composite material. Tension tests were completed on various specimens with widths of 1 in., 2 in. or 3 in. and a constant width to hole diameter ratio of 4. The composites tested were warp knits with AS4 fibers and 3501-6 resin. Test results show a small percent change of net strength with stitch location. However, due to the large scatter in data, the small 6% change in net strength is considered negligible.

Introduction and Background

There is strong interest in using composite materials for primary airplane components. The chief advantage of composites over presently used metals is the low density of composites compared to the high density of metals. The overall weight of an airplane would be reduced thereby reducing fuel consumption. Another advantage of using composites is the stiffness of the material. By using composites, future airplane wings will have a higher aspect ratio of length to width because of the increased stiffness of the wings. This results in a more economical plane because high aspect ratio wings reduce the drag on an aircraft. The third advantage of composites over metals is that composite strength and stiffness can be tailored. Components of an aircraft will need extra strength in certain directions depending on the design of the component. Anisotropic composites can have increased strength and stiffness in different directions by laying extra fibers in the directions of the needed extra strength.

Although there are many benefits in using composite materials, the present cost of manufacturing composites is high compared to the costs of manufacturing metals. As a result, an effort has been made to develop cheaper methods of fabricating composites without a large decrease in strength or stiffness. One of these new methods being researched is mechanically stitching dry textile preforms. Fibers in the dry fabric are oriented in different directions, depending on where the most strength is needed, and then sewn together by machine. After being stitched together, the material is cut to the desired size and shape. Resin is used to harden the material, and bind the layers together. This was accomplished by resin transfer molding (RTM), in which the material is impregnated with resin and cured. This new method has been proven to be more cost effective than present manufacturing techniques. Stitching has also been found to reduce delamination after impact.

Before stitched composites can be used regularly in commercial aircraft, the mechanical properties of composites must be tested. Further tests are needed to determine the ability to machine and fabricate final products from stitched composite parts. One concern about the fabrication of the final components was the effect of hole placement near a stitch. The area surrounding a stitch tends to have a pocket for resin which may make that area weaker than the rest of the material. Since higher stress concentrations exist around a hole, there was concern over whether the material would be weaker in this area if a hole was drilled in a resin enriched area near a stitch. Therefore, the combination of high stresses between a hole and a stitch needed to be examined. Open-hole tension tests determined if the distance between the edge of a hole and a stitch affected the ultimate strength of a specimen.

Materials

All of the specimens tested were warp knit with 44% AS4 fibers in the +/- 45° and 0° directions and 12% AS4 fibers in the 90° direction. The A specimens had all seven layers stitched at once, whereas the H1 specimens had the +/-45° and 0° layers stitched together as a group, and then a layer of 90° was stitched between two groups of +/-45° and 0°.

Each row of stitches was sewn at 0.25 in. from the previous row in all three specimen widths. Different stitch diameters were considered for testing. The diameter of the stitches for the

H1, A1, and A2 specimens was 0.0313 in. (1/32). This type of stitch was tested for the three width sizes of 3 in., 2 in., and 1 in. However, for the A3 specimens a smaller stitch diameter of 0.156 in. (1/64) was tested. The reason for testing a small diameter stitch was a small diameter might leave a smaller area or pocket than a large diameter stitch. Since resin tends to collect in pockets near a stitch, a small area around a stitch was believed to collect less strength-reducing resin than a large area around a stitch. However, this small diameter stitch was tested only in the 1 in. wide composites.

Different diameter holes were core drilled into the specimens. This type of drilling involves a cylindrical-shaped drill-bit grinding a hole through the material. The ratio of the width to the hole diameter of each specimen was kept constant at 4. The hole diameters were 0.25 in., 0.5 in., and 0.75 in for the width sizes of 1 in., 2 in., and 3 in. respectively. The edge of the holes were located either touching a stitch, close to a stitch, or far from a stitch. For each specimen width, at least 3 specimens were tested with each hole location. A sample specimen can be seen in Figure 1.

Procedures

Each specimen was measured, with a caliper, for width, thickness, diameter, and distance of the longitudinal tangent of the hole from the nearest stitch. The width and thickness were needed to calculate the cross sectional area of the specimen. The thickness of the specimen was measured on both sides of a hole, and the average of the two measurements were recorded as the thickness. The diameter of the drilled hole was measured to check for consistency. The distance of the longitudinal tangent of the hole from the stitch was measured in order to compare the hole placements of each sample.

After each specimen was measured, the ends of the specimens were taped to protect the grips of the tension machine. The specimen was placed squarely in the lower grip of the tension machine and the upper grip was maneuvered around the upper portion of the specimen and closed. The machine applied a load to the specimen at a rate of 0.05 in./min. until fracture. The ultimate tensile load was recorded from each experiment for later comparison. Specimens were tested in groups according the width, and then hole placement with the largest specimens tested first.

The tension testing machine for the largest specimens of 3 in. width was a Materials Testing Machine (MTS) Hydraulic Fatigue Test System, with a 100 KIP capacity. The machine was controled with a MTS 458.20 microconsole. For the two smaller widths of 2 in. and 1 in., a MTS Hydraulic Fatigue Test System, with a 50 KIP capacity and MTS 458.20 microconsole was used for testing. A computer was connected to the microconsoles to read the output signals. The data acquisition software program plotted the load vs. the grip stroke.

Results

The net open-hole tensile strength of the each specimen versus the distance of the edge of the hole from the stitch was graphed. The net strength allowed for specimens of different cross sectional areas to be compared. Calculations of the net strength were made by the following formula:

(1) $$\text{Net Strength} = \text{Load} / ((\text{Width}-\text{Diameter}) * \text{Thickness})$$

The average net strength of all the specimens by type, by size, and by the location of the edge of the hole can be seen in Table 1. The net strength was used to calculate the percent of scatter in the data. The difference between the highest and lowest net strengths of specimens with the same size, stitch diameter, and stitch technique were divided by the net strength of the highest specimen as in the following equation:

(2) $$(\text{Highest net strength} - \text{Lowest net strength}) / \text{Highest net strength}$$

For the largest width size of 3 in., both the H1 and the A2 specimens were graphed together for comparison between materials. As can be seen in Figure 2, the distance between the edge of the hole and the stitch did not affect the ultimate strength of either material. The average strength of the H1 material with the edge of the hole close to the stitch (HC), was compared with the average of the H1 with the edge far from the stitch (HF). Although there was a slight 2.3% decrease in the average strength of the H1 specimens from HC to HF, Figure 2 shows the scatter of the data points was as high as 7.4%. With this high percentage of scatter, it can not be concluded that the strength changed significantly when the distance between the edge of the hole and the stitch decreased. The average net strength of the A2 specimens with the edge close to the stitch (A2C) was 79.33 ksi, and the average net strength of the specimens with the hole far from the stitch (A2F) was 73.82 ksi. The A2 specimens similarly showed a decrease in average net strength of 6.9%, but with as much as a 10.5% scatter of data. Since the scatter of data was higher than the change from A2C to A2F, it was concluded that the change was negligible. Figure 2 also shows that the open-hole tension strength of the H1 and A2 Specimens are similar even though the H1 has a different stitching technique

Results from the tests with the 2 in. wide H1 and A1 specimens are shown in Figure 3 and Figure 4. In Figure 3, the average net strength of the H1 with the edge close to the stitch (HC) was 78.24 ksi. This strength is 1.8% less then the average net strength of 79.65 ksi for the H1 with the edge far from the stitch (HF). The percent scatter of the points was 11.4%, which was higher than the decrease in net strength of 1.8%. As a result, the change in strength was negligible when compared to the higher percent scatter of data. As can be seen in Figure 4, the average net strength of the A1 specimens that had the edge close to the stitch (A1C) was 86.04 ksi. The average net strength of the A1 specimens that had the edge far from the stitch (A1F) was 86.28 ksi, which was less than 1% higher than the A1C specimens. This change in average net strength was especially low when compared to the other tests. Since the 21.7% scatter of data was significantly higher than the change of net strength, the change in net strength was considered to be negligible. The average strengths of the H1 for the 2 in. wide specimens was lower than the A1 specimens even though the H1 had a different stitching technique.

The results of the 1 in. wide specimens can be seen in Figure 5, Figure 6, and Figure 7. In Figure 5, the H1 specimen with the tangent close to the stitch (HC) had an average net strength of 90.65 ksi. This net strength was 5.7% lower than the net strength of 96.16 ksi for the H1 with the edge far from the stitch (HF). However, the scatter of data was 15.5% which was higher than the percent change in the net strengths of the specimens. The change in strength from HC to HF was considered to be negligible since the percent scatter of data was higher than the percent change in strength. In Figure 6 it can be seen that the A1 specimen with the edge close to the stitch (A1C) had an average net strength of 93.97 ksi. The A1C net strength was 8.0% lower than the average net strength of 102.17 ksi for the A1 specimen with the edge far from the stitch (A1F). However, since the scatter of data was 13.5%, the 8.0% change on net strength was considered negligible. A third set of tensile tests was conducted with 1 in. wide A3 specimens These specimens had a smaller stitch diameter of 0.0156 in. as compared to the stitch diameter of 0.0313 in. used in the A1 and H1 specimens. As can be seen in Figure 7, the average net strength of the A3 specimens with the edge close to the stitch (A3C) was 94.25 ksi. This net strength was 7.8% lower than the average net strength of 102.17 ksi for the A3 specimen with the edge far from the hole (A3F). The scatter in data was 12.4%, which was more than the change in net strength.

Conclusions

In conclusion, all the specimens had a percentage of scatter higher than the percent change in net strength. As a result, there was no significant change in strength due to hole location near a stitch. Future tests should focus more on why the percent scatter of data was so high, and more tests with hybrid material. Hybrid material uses the same stitching technique as the H1 specimens but has stronger IM7 fibers in the 0° direction.

References

Hawley, Arthur V., "Development of Stitched / RTM Primary Structures for Transport Aircraft," NASA Contractor Report 191441, NASA Contract NS1-18862, July 1993.

Table 1

Material	Width (in.)	Ave. Net Strength (ksi)	Material	Width (in.)	Ave. Net Strength (ksi)
Hybrid Close (HC)	3	77.27	Hybrid Close (HC)	1	90.65
Hybrid Far (HF)	3	75.45	Hybrid Far (HF)	1	90.16
A2 Close (A2C)	3	79.33	A1 Close (A1C)	1	93.97
A2 Far (A2F)	3	73.82	A1 Far (A1F)	1	102.17
Hybrid Close (HC)	2	78.24	A3 Close (A3C)	1	94.25
Hybrid Far (HF)	2	79.65	A3 Far (A3F)	1	102.17
A1 Close (A1C)	2	86.04			
A1 Far (A1F)	2	86.28			

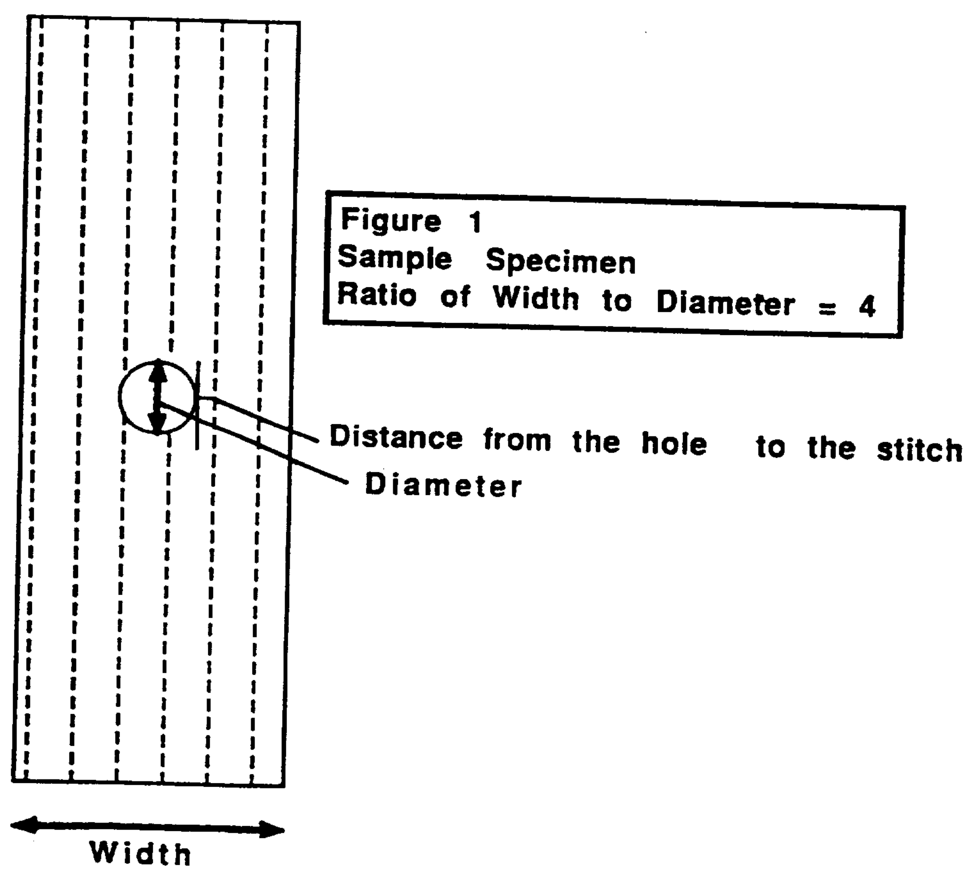

Figure 1
Sample Specimen
Ratio of Width to Diameter = 4

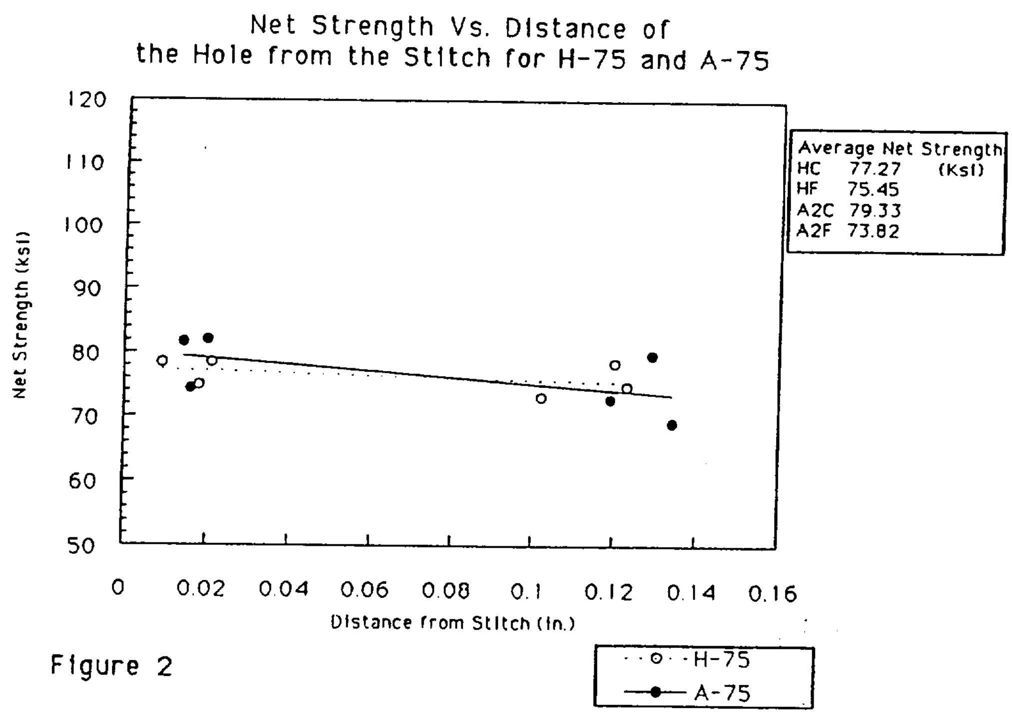

Figure 2

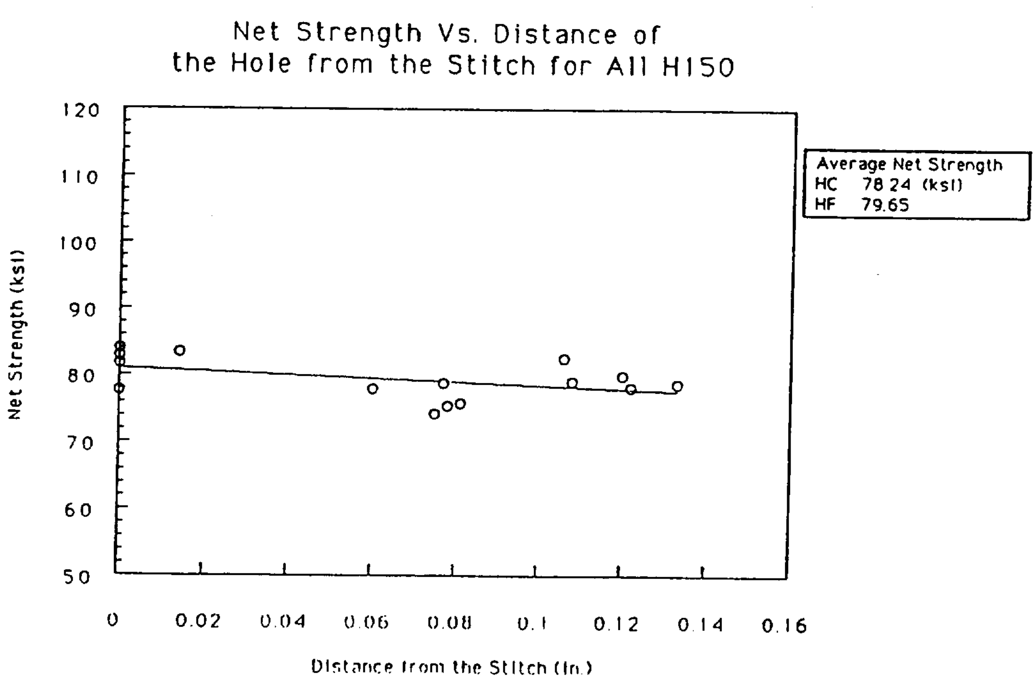

Figure 3

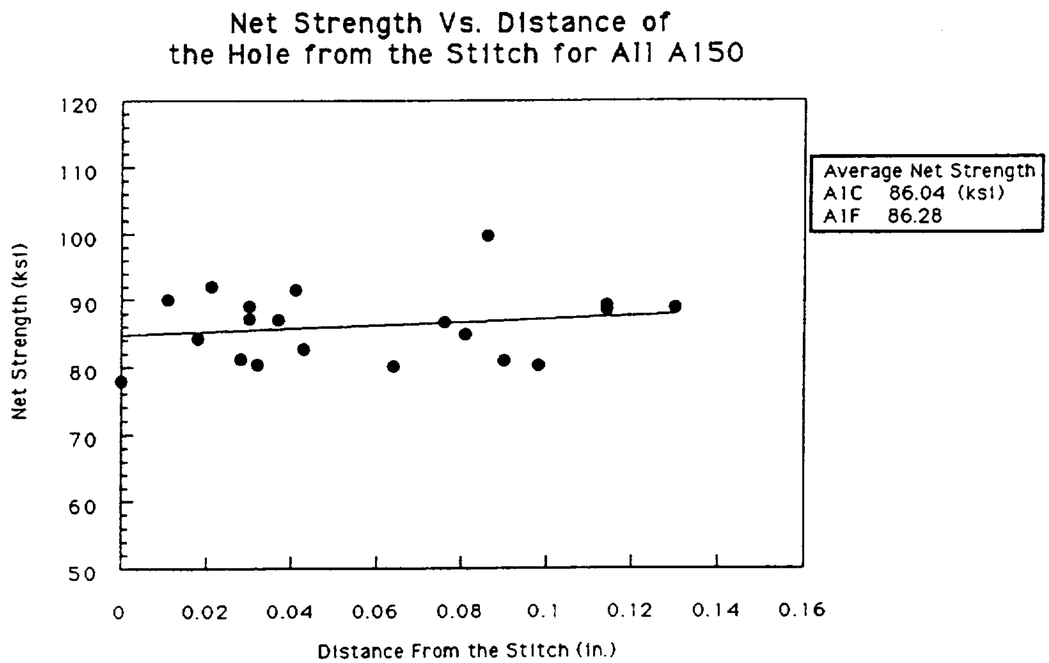

Figure 4

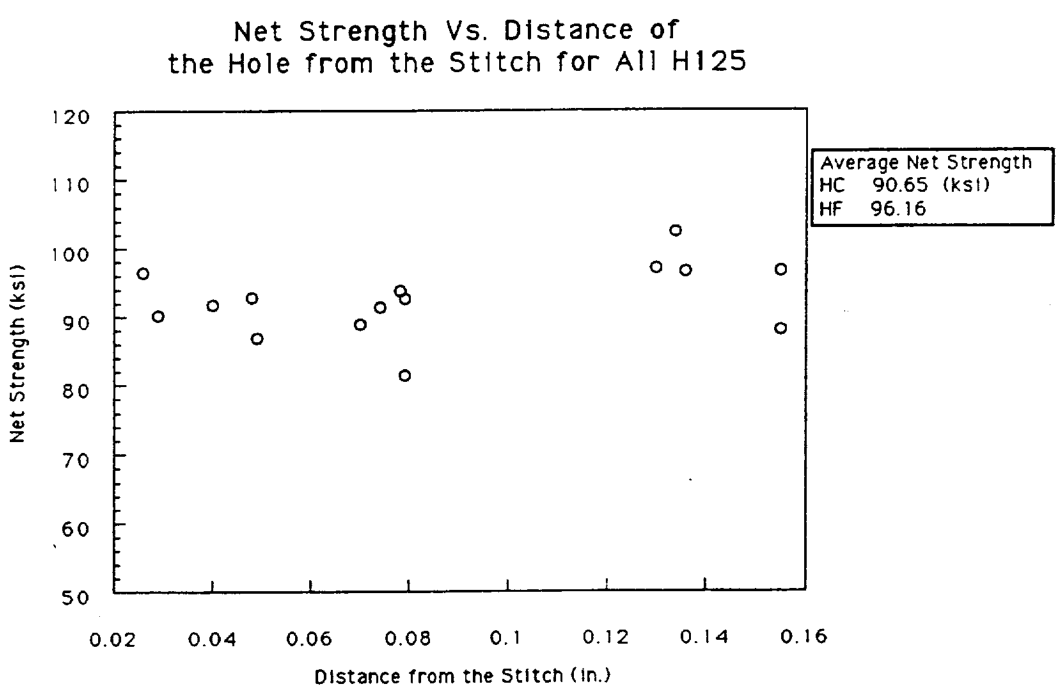

Figure 5

Net Strength Vs. Distance of the Hole from the Stitch for All A125

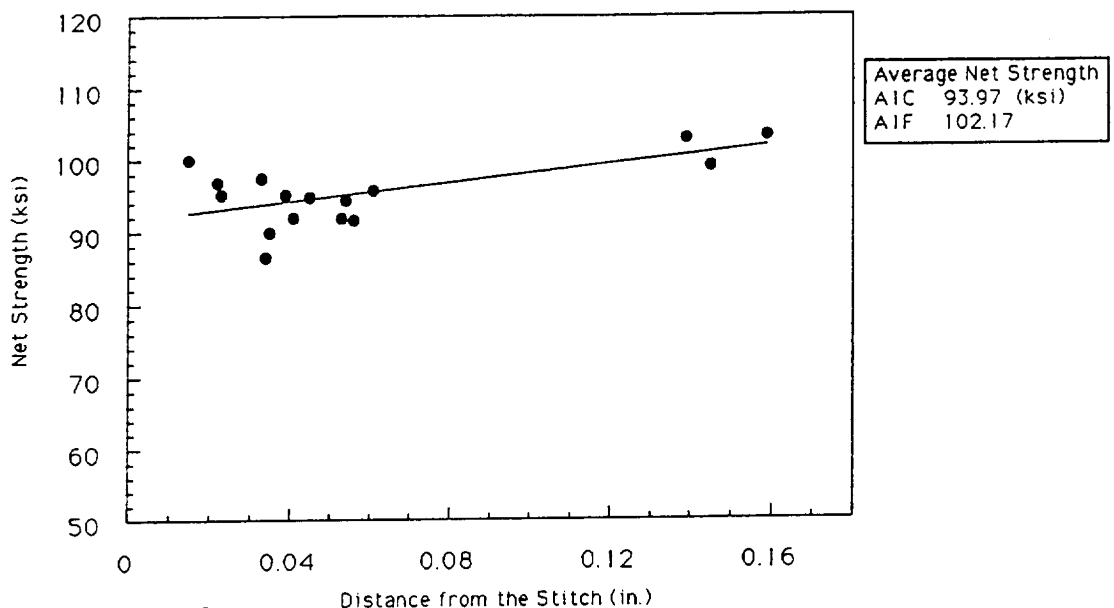

Figure 6

Net Strength Vs. Distance of the Hole from the Stitch for All A325

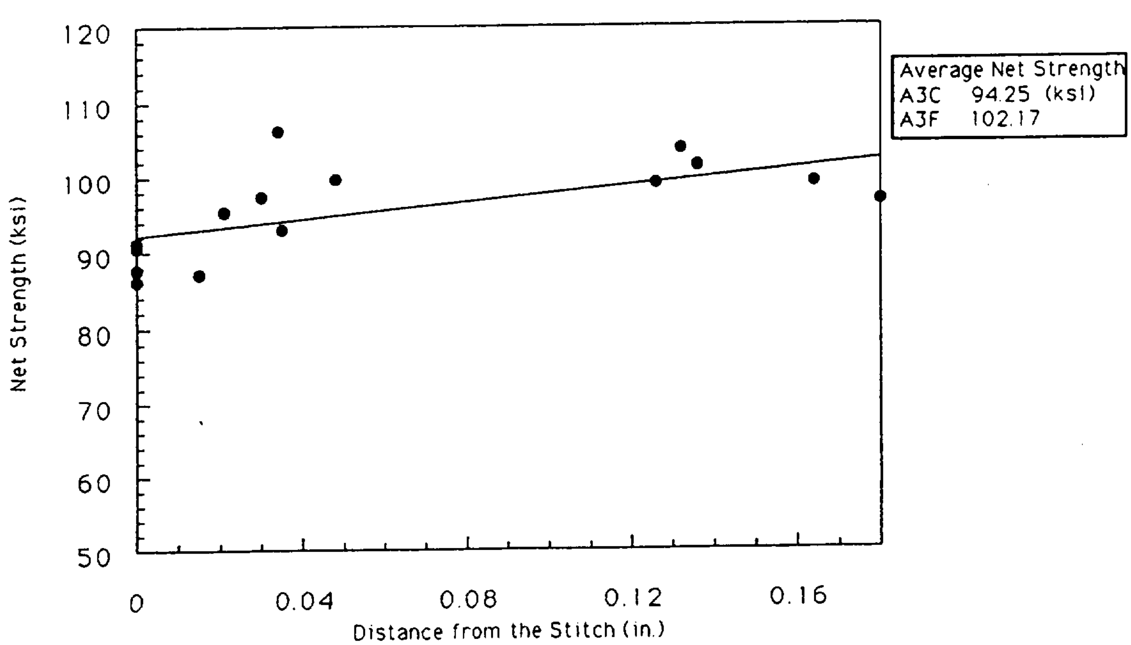

Figure 7