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Analytical Approach to Estimate and Optimize the Defects in Prepreg Lamination for a Component Produced by Stacking of Blanks from a Cutter

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Abstract: Carbon Fiber-reinforced polymer composite materials are fast gaining ground as preferred materials for the aero engine components. For the easiness of manufacturing instead of traditional fiber and resin layup process, the composites are manufactured using laminate sheets of composite made with layers of prepreg (carbon fiber pre-impregnated with Resin) sheets which are stacked with different ply orientation (Ex: +45°,-45°). For different size and shape of components only standard size prepreg sheets are available. While doing layup process gap between two prepreg sheets is unavoidable. These gaps may cause some weak spots in the laminate. While fabricating the components these weak spots in laminates may overlap when stacked which further weakens the component. To study the impact of such weak spot overlap, complex FE analysis is required which may take significant efforts. However, it is possible to avoid such complex FE analysis if there is methodology in place which can prove that the occurrence of weak spot overlap is acceptably low and FE analysis of these worst components can be easily determined. For the aerospace components where strength cannot be compromised, it is necessary to make sure these kind of weak spots occurrence are under the control in the component. The methodology explained in this paper can also be used to optimize the layup process to avoid the possible weak spots.
Keywords: Point Defect, Composite, Stack, Prepreg Laminate.

I. INTRODUCTION

Carbon fiber composites offer many advantages when compared to metallic alloys, especially where high strength and stiffness to weigh ratio is concerned. Additionally, they provide excellent fatigue properties and corrosion resistance in applications. With all these advantages, composite structures have gained widespread use in the aerospace industry during the last decades. Generally carbon fiber composites used in the Aerospace industry are manufactured by fabricating several superimposed laminates, each laminate consisting of several unidirectional non-woven fibers of carbon called prepreg, at least some of the different prepregs extending in different directions.

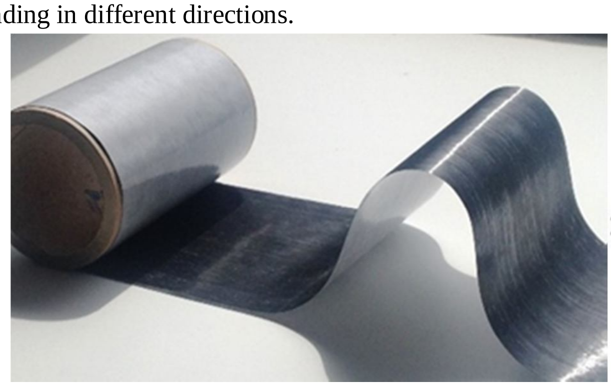

Fig 1: Ply

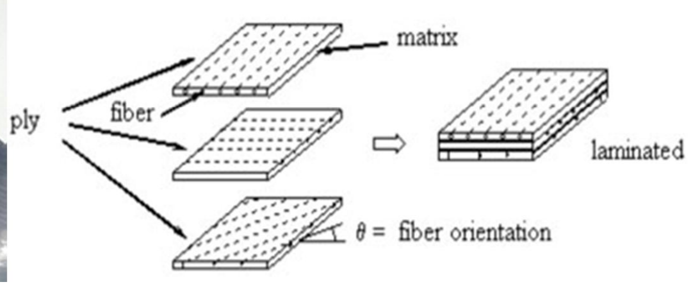

Fig 2: Laminte generation

Depending on the material properties desired, direction of the fibers is defined (ref fig 2). These laminates are cut into required shape known as “cutup” (shape of one layer of a component) and are stacked up using hot press to meet the component definition. Sample layup of a typical composite component is as shown in the figure below. Fabrication of a complex part geometry requires a sophisticated layup definitions such as tapered plies which promotes the formation of gaps.

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The prepreg plies are only available in standard sizes irrespective of the size and shape of the component, hence when connected in series to meet the component dimensions, a parallel gap between two prepreg plies is inevitable. During fabrication of a laminate, these gaps formed in one layer when intersected with a gap in another would result into a **defect point**. Measures should to taken to minimize the overlapping of defects points during stacking of laminates termed as **defect**, as it could impact the strength in the vicinity thereby impacting strength of the vane. To minimize these defects, cutter profile should be arranged in such a way to avoid defect point also to optimize the cutter for maximum material utilization of material. Finding these defects manually is difficult as the length of each layup will be very long (i.e. 2-5 meters).

A. Laminate Preparation

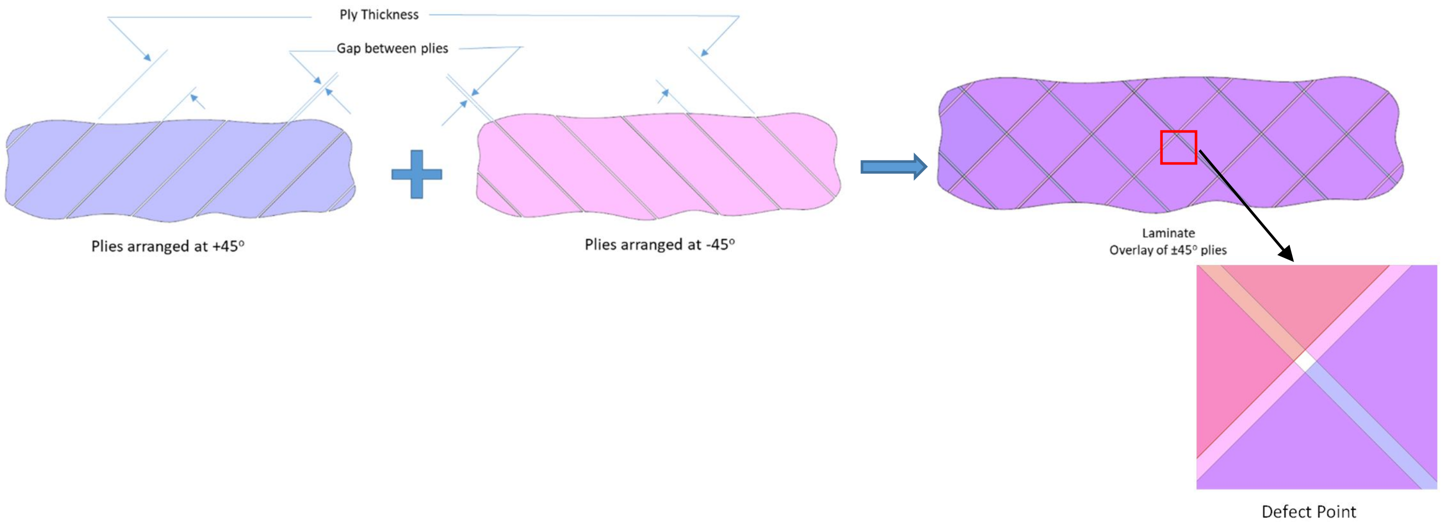


Fig 3: Laminate Preparation

B. Cutter

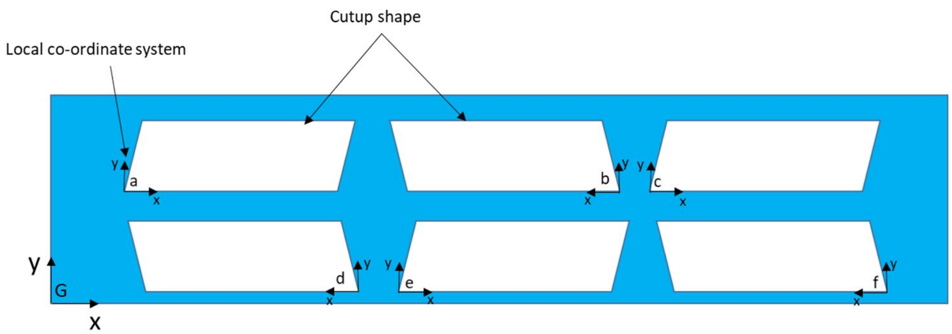


Fig 4: Cutter

C. Generation of Cutups

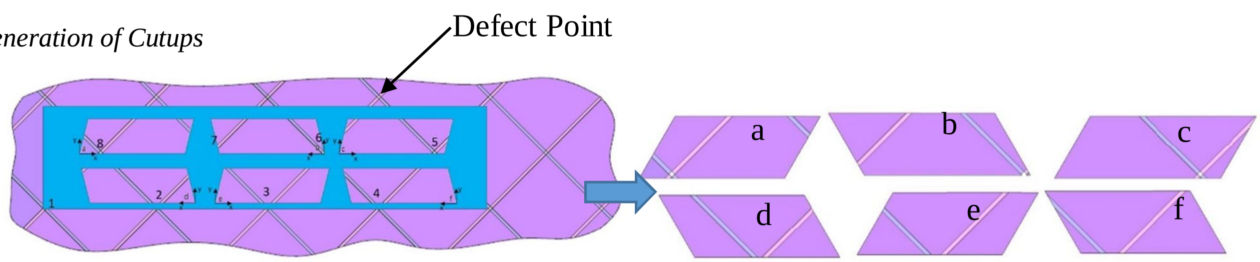


Fig 5 : Cutter & Laminate

Fig 6: Laminate cutups

II. METHODOLOGY

1) Cutup shapes or laminate layer shapes are distributed on cutter in such a way that there is minimum wastage.
2) Each laminate layer has its own local coordinate system and a common global coordinate system.
   The bottom left corner of the cutter is considered as Global Origin (G).
   Aligning features/stacking points are considered as local co-ordinates. Also the orientation depends on the cutup orientation in the cutter

3) The location of defect point inside a layup is not fixed, so they may come anywhere within a layup. But the pattern of defect points in a layup is fixed.

Let us consider

The first defect point is at global co-ordinates.

$(x1,y1)=(0,0)$

Assume Width of the ply is 100.

The relation between the points is defined from the preceding point by considering the cutup layout as shown above

2nd point $(x2,y2)=(x1+\sqrt{100^2+100^2},y1)$

3rd point $(x3,y3)=(x2+\sqrt{100^2+100^2},y2)$

4th point $(x4,y4)=(x3+\sqrt{100^2+100^2},y3)$

5th point $(x5,y5)= (x4+\sqrt{100^2+100^2}/2, y4+\sqrt{100^2+100^2}/2)$

6th point $(x6,y6)=(x5-\sqrt{100^2+100^2},y5)$

7th point $(x7,y7)= (x6-\sqrt{100^2+100^2},y6)$

8th point $(x8,y8)=(x7-\sqrt{100^2+100^2},y8)$

4) Defect points on different laminate layer may align at same location when stacked.
5) To identify such matching defects, the relative position of defects in each laminate layer should be established from a common point (i.e. Stack point/origin of local co-ordinate system).
   Let (xa,ya) be the stack point co-ordinate of the cutup a then location of defect point 1 w.r.t cutup a is
   $(xa1,ya1) = (xa-x1,ya-y1)$
   Similarly find the point co-ordinates of all the points from all the cutups.
6) Align all the cutups w.r.t. stack points
7) Find the matching defects.
8) Increment the location of defect pattern w.r.to global and to repeat the above step.
9) Same process is repeated until the entire layup is covered.

A. Working Procedure

1) Iterate the first defect point in global coordinate system and generate the points in the local coordinate system (i.e. a, b, c, d, e and f).
2) For each value of defect point in local coordinate system comparison is done with all the other local coordinate systems i.e. values in a, b, c, d, e & f are compared with each other.

a) For instance comparison is done in the following order, a to (b, c, d, e & f), b to (c, d, e & f), c to (d, e & f) … e to f
b) Matched points are obtained from this comparison

3) There is a criterion applied to find out these matching points, which is explained in "2.2.Criterion for matching points" section of this document.
4) It is checked whether the matched points lie inside the boundary of that particular cutup. Algorithm used to check if a point lies inside a boundary is explained in "2.3.Algorithm to check if a point is inside a boundary" section of this document.

B. Criterion For Matching Points

If two defect points in different laminates from respective local co-ordinates match at same location then it is called a defect. Considering 'X' as the gap between two plies of the laminate, figure shows the criterion of matching defects in different laminates based on geometry.

1) Therefore criterion for the occurrence of a matching defect will be Distance b/w two defects is ≤ √2*X mm (Refer fig. 7).

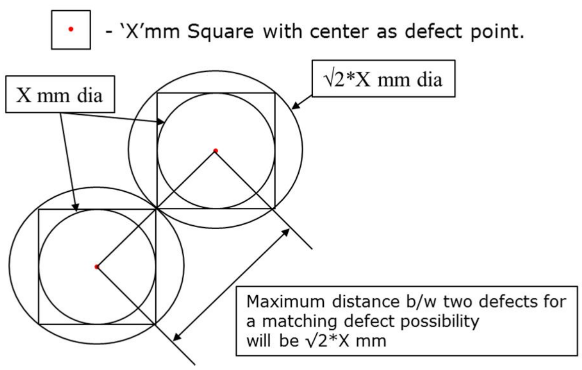


Fig7: Condition to check for overlap

C. Algorithm To Check If A Point Is Inside A Boundary

After finding defects it is necessary to know whether these matching defects are falling inside laminate boundary or not. To find out following algorithm is used.

1) *Logic:* If a point lies in a polygon then sum of angles made between lines obtained by joining that point to vertex points will be equal to 360 degrees.

2) If the point is inside the boundary then $\theta1 + \theta2 + \theta3 + \theta4 + \theta5 = 360^0$

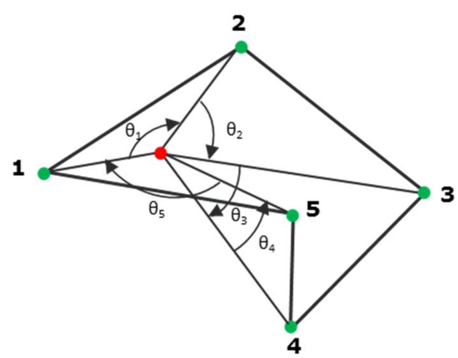


Fig 8: Condition for a point to be inside the boundary

3) If the point is outside the boundary then $\theta1 + \theta2 + \theta3 + \theta4 + \theta5 = 0^0$.

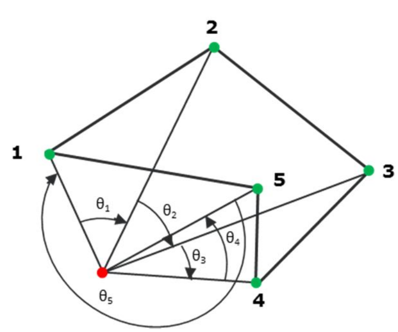
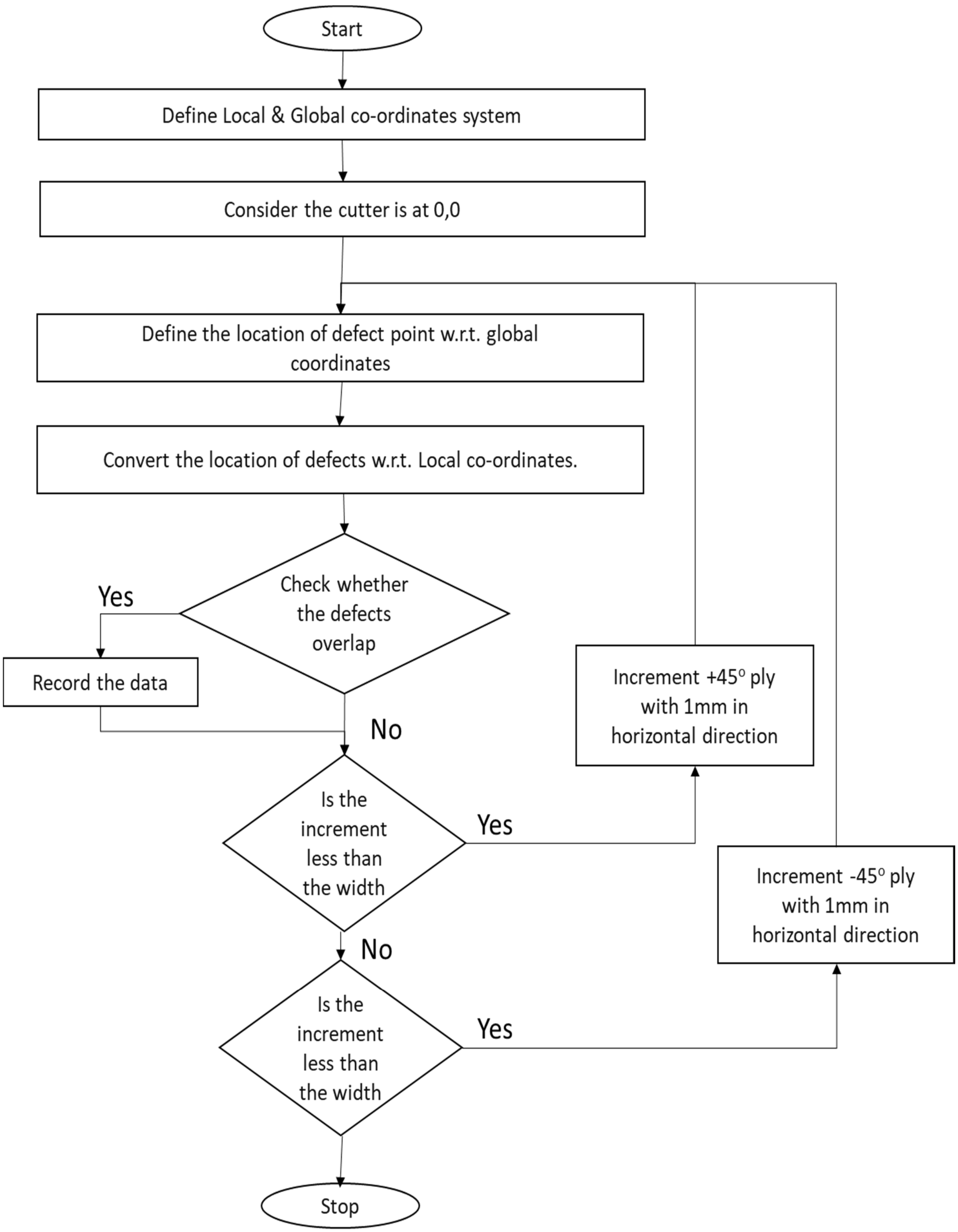


Fig 9: Condition for a point to be outside the boundary

4) Therefore if there are ‘n’ number of boundary points and the defect point lies within boundary then $\theta 1 + \theta 2 + \theta 3 + \theta 4 + \ldots\ldots\ldots + \theta n = 360^0$

Flowchart



D. Results

In the results, matching points in the whole layup (i.e. matching points outside and inside the laminate boundary) are included. From this by applying the logic mentioned in "II-B. Algorithm to check if a point is inside a boundary" matching points which are inside the boundary are determined. And the final results include matching points inside the laminate boundary.

Matching points locations in both Global and local coordinate system are mentioned in results. The coordinate systems in which the matching occurs are also mentioned.

Xg	Yg	Point in Global		Point in Local		Coordinate system name
246	354	246.00	354.00	608.46	10.28	A
		1462.22	354.00	608.68	10.28	B
550	354	550.00	354.00	304.46	10.28	A
		1158.11	354.00	304.57	10.28	B
395	409	395.00	409.00	459.46	-44.72	A
		1307.17	104.94	460.12	-45.27	E
699	409	699.00	409.00	155.46	-44.72	A
		1003.06	104.94	156.01	-45.27	E
315	348	923.11	348.00	69.57	4.28	B
		2139.34	348.00	70.12	4.78	C
619	348	1227.11	348.00	373.57	4.28	B
		1835.22	348.00	374.23	4.78	C
161	402	1377.22	402.00	523.68	58.28	B
		1681.28	97.94	523.18	58.84	D
465	402	1073.11	402.00	219.57	58.28	B
		1985.28	97.94	219.18	58.84	D
398	410	1006.11	410.00	152.57	66.28	B
		702.06	105.94	153.40	65.84	F
702	410	1310.11	410.00	456.57	66.28	B
		397.94	105.94	457.51	65.84	F
550	562	1462.17	257.94	608.62	-85.77	B
		245.94	257.94	609.51	-86.16	F
160	404	1984.34	404.00	225.12	-51.22	C
		1072.17	99.94	225.12	-50.27	E
464	404	1680.22	404.00	529.23	-51.22	C
		1376.17	99.94	529.12	-50.27	E
310	458	1830.28	153.94	374.18	2.84	D
		1222.17	153.94	375.12	3.73	E
614	458	2134.28	153.94	70.18	2.84	D
		918.06	153.94	71.01	3.73	E
243	465	1155.17	160.94	308.12	10.73	E
		547.06	160.94	308.40	10.84	F
547	465	1459.17	160.94	612.12	10.73	E
		242.94	160.94	612.51	10.84	F

Table: Matching points inside boundary details

When all laminate layers are stacked and their respective matching points are as shown in the figure below.

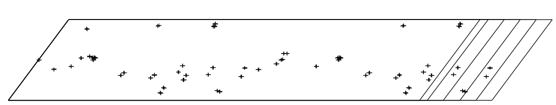


Fig 10: Stacked laminate layers (i.e. single Laminate) and defect points

A composite can be made by stacking no. of such laminates cutups. While stacking different laminates there also could be chances for defects matching which causes a weak spot in the final composite

Distance b/w every two defects is calculated and matching points criterion is applied to find number of matching defects occurring in a composite.

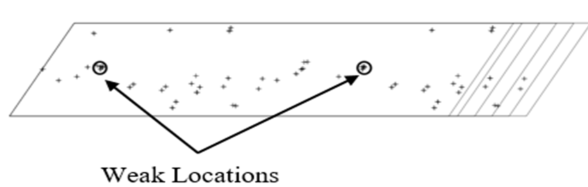


Fig 11: Stacked laminate layers (i.e. single Laminate) and defect points

III. CONCLUSION

In this paper, it is explained how defects may occur during layup process in a laminate and how the gap between plies causes these defects. Further, the process followed to find out these defect points in a Prepreg laminates is discussed. The exact no. of defects and their location can be found out precisely with this process in composite. After finding the defects in laminate further it is discussed how these defects in laminates may cause a matching defects when two or more laminates are stacked during fabrication. Finding matching defects in laminates will give the weak locations in a component. It is evident that the layup of layers of prepreg plies will decide the number of defects will occur in a laminate. By following the process explained in this paper one will come to know the optimum layup of plies to decrease the number of defects occurring in a laminate. Eventually by this method we can decrease the defects in a composite during manufacturing process by optimizing the cutter profile. The obtained worst component produced form the optimized cutter is analyzed by FE modelling for strength.

A. *Scope For Future Study*

In this paper only point defects are considered. This may be extended to line defects also i.e. overlap of lines which will also weakens the component produced. If this condition is simulated then predicting the worst case component and finding out its strength is easy. If worst component produced in with in the limit then the whole manufacturing process/cutter profile is accepted as is.

B. *Glossary*

1) *Prepreg:* Pre-impregnated fiber of uni-direction
2) *Laminate:* Layers of prepreg arranged with required orientation
3) *Cutter:* Tool used to cut laminate as per required shape.
4) *Cutup:* Blanks obtained from blanking of laminate with cutter.
5) *Defect Point:* Gap area formed when gap in one layer intersected with a gap in another layer.
6) *Defect:* Overlap of defect points.
7) *Weak point/Weak Location:* Overlap of two or more defect points

REFERENCES

[1] "FIBER METAL LAMINATES MADE BY THE VARTM PROCESS" by B. J. Jensen & R. J. Cano.
[2] http://math.stackexchange.com/questions/237/how-do-you-determine-if-a-point-sits-inside-a-polygon