CHAPTER 4

PROPOSED JOINT CONFIGURATIONS

4.1 INTRODUCTION

The honeycomb sandwich panels are prepared using various types of resins. It is necessary to select the appropriate resin for the selected panel material based on its effectiveness. Further, during the construction, the joints are inevitable. It is useful to study various configurations of joints with respect to its strength systematically. Hence, the present chapter is devoted for the complete analysis of various resins for its suitability with aluminum material and the details regarding the edging preparations, inserts and forming of various joint configurations.

4.2 SELECTION OF RESINS FOR ADHESIVE JOINTS

It is perceived that joining of sandwich panels is quite cumbersome due to the heterogeneous nature of the panel as hexagonal Al core is embedded between two face sheets. The joint configuration should be conceived such that perfect flatness of the panel after joining along with consistency of joint efficiency should be ensured. Further, the adhesive used for joining should possess excellent wetting characteristics and must be able to quickly cure to attain full strength. Keeping the above points, three commercially available thermo-set type resins, namely viz, AW 106 (Araldite with hardener HV953U), AV 138 (Araldite with hardener HV908) and Epoxy 951 are selected as candidate adhesive resins for joining aluminium
honeycomb core Sandwich panels. The properties of the resins considered are briefed below.

4.2.1 Araldite AW 106

It is a multipurpose resin contains two different compounds and one of them usually a hardener available in paste form. It is cured at room temperature. It is suitable for bonding a wide variety of metals, ceramics, glass, rubber, rigid plastics and most other materials in common use. It is a versatile adhesive for the craftsman as well as most industrial applications. On curing it has desirable properties like high shear and peel strength, Tough and resilient, offers resistance for dynamic loading.

4.2.2 Araldite AV 138

It is used with the hardener (HV 998 epoxy adhesive). It is in the form of paste and cured at room temperature. The cured epoxy adhesive performs well at elevated temperatures up to 120°C and offers high chemical resistance. It is suitable for bonding a wide variety of substrates including metals, ceramics, glass, rubbers and rigid plastics. It is a low out-gassing material that is suitable for the use in specialized electronic telecommunication and aerospace applications.

4.2.3 Epoxy Resin 951

It is used in places that require superior adhesion is necessary. It is a thermosetting type and cures by the heat generated internally. It is well suited to bond components like wood, fiberglass, metal, concrete, glass, and various types of plastics. Further, it prevents rusting of metal due to moisture.
4.2.4 Application Procedure of the resin

Initially, an etchant paste has to be prepared and applied to remove the oxidation layer on the surface. It consists of aerosil powder, $\text{H}_2\text{SO}_4$, distilled water and sodium dichromate. A mixture of 50gm of $\text{H}_2\text{SO}_4 + 80$gm of distilled water + 17gm of sodium dichromate is made that yields a red colour solution. Further, aerosil powder is added to the above solution till it turns into a Brown colour paste. It is applied over the surface to be bonded and allowed to cure for 10 minutes. Then the paste is removed from the surface using wet cloth. Now the surface will be free from oxide layer. The above resins require careful handling both before and after applying them on the surface to be bonded. It is advisable to use hand gloves to protect our hands.

Further, the appropriate resin in the form of paste is applied over the surface to be bonded. In the case of AW 106 resin, a ratio of 60:40 (Resin/Hardener) is mixed till the colour of the paste becomes Ivory. In the case of AV 138 resin, a ratio of 60:40 (Resin/Hardener) is mixed till the colour of the paste becomes dark gray. In the case of 951 resins, a ratio of 90:10 (Resin/Hardener) is mixed till the paste becomes colour less. After applying the resin, the joint is held rigidly and cured for 4 hours.

4.2.5 Performance Evaluation of Resins on Aluminum

The performance of the resin is evaluated by applying it to the aluminum metal surfaces and testing them under shear load after curing. As the proposed sandwich structure is made-up of aluminum, the bonding characteristic of the resin with aluminum is tested. As our primary aim is to test the bonding strength produced by resins, instead of sandwich panel pure aluminum blocks of same grade is selected for the test. The aluminum specimens of grade A3003 are machined to the dimensions of 25×25×10 mm
and they are bonded using the different resins as per the procedure explained above. The specimens after curing are shown in the Figure 4.1.

![Figure 4.1 Direct shear test specimens](image)

Testing for shear strength is carried out as per ASTM C273 standard. In order to determine the load at which the resin film will fail, the shear load is applied to the specimens. In order to determine the shear strength of the resins, direct shear test has been devised as shown in the Figure 4.2(a) and Figure 4.2(b) indicated below. The test comprises of resin sandwiched between three thick Al sheets. The outer block provide the support reactions and the load is applied on the central Al block.

![Figure 4.2(a) Direct shear test set-up](image)  ![Figure 4.2(b) Concept in direct shear test](image)

The load is applied on the specimen using digital flexural test system till shearing of the specimen occurs. Specimen is placed between two
circular plates such that bottom plate is fixed and top plate is moving. The results of the direct shear tests are indicated in Table 4.1.

Table 4.1 Results of direct shear test on resins

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Bond area (mm$^2$)</th>
<th>Load at failure (kN)</th>
<th>Shear strength (MPa)</th>
<th>Avg. shear strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AW 106 - 1</td>
<td>1028.00</td>
<td>7.33</td>
<td>7.13</td>
<td>7.34</td>
</tr>
<tr>
<td>AW 106 - 2</td>
<td>1032.00</td>
<td>7.66</td>
<td>7.42</td>
<td></td>
</tr>
<tr>
<td>AW 106 - 3</td>
<td>1052.00</td>
<td>7.86</td>
<td>7.47</td>
<td></td>
</tr>
<tr>
<td>AV 138 - 1</td>
<td>1040.00</td>
<td>8.70</td>
<td>8.37</td>
<td>8.48</td>
</tr>
<tr>
<td>AV 138 - 2</td>
<td>769.60</td>
<td>6.73</td>
<td>8.74</td>
<td></td>
</tr>
<tr>
<td>AV 138 - 3</td>
<td>696.60</td>
<td>5.81</td>
<td>8.34</td>
<td></td>
</tr>
<tr>
<td>951 - 1</td>
<td>960.00</td>
<td>2.07</td>
<td>2.16</td>
<td>1.64</td>
</tr>
<tr>
<td>951 - 2</td>
<td>960.00</td>
<td>2.07</td>
<td>2.16</td>
<td></td>
</tr>
<tr>
<td>951 - 3</td>
<td>960.00</td>
<td>0.57</td>
<td>0.59</td>
<td></td>
</tr>
</tbody>
</table>

The above table the bonding capacity of various resins has been carried out by evaluating the stress when a particular resin is applied over the aluminum material. As the stress is evaluated the area is not kept constant for all the specimens. The third specimen with the resin 951 has yielded very low value of stress and it is due to improper curing and application that resulted during the fabrication of the specimen.

4.3 VARIOUS CONFIGURATIONS OF JOINTS

It is well perceived that joining of sandwich panels is quite cumbersome due to its heterogeneous nature. The core of the panel is embedded between two face sheets and the flatness is maintained to achieve better joint efficiency. Further, the proper adhesive or resin is used for joining
the face sheets with core. The resin is selected in such a way that it possess excellent wetting characteristics and capable of curing in shorter time to yield maximum strength. The preparation of the joint involves three stages that are listed below.

4.3.1 Edging

The edge of the faying face is to be shaped to form the joint jointed so as to yield smooth surface and to yield maximum strength. It is accomplished by compressing the edges using specially designed fixtures. The shaping of the edges is carried out using flexural testing machine with the aid of fixtures so as to have uniformity and accuracy of the edge thickness. The fixtures and detailed process of forming the faying face edges are briefed in the forthcoming sections with sketches.

4.3.2 Joining

The joints are made with or without inserts by applying adhesives. Usually, the inserts will be of same material as that of the panel. The joints are prepared with or without inserts to have uniform top and bottom surfaces after joining. The inserts also serves in increasing the joint area to apply adhesives and to obtain good strength after curing. The selection of adhesives with respect the aluminum material is discussed in Section 4.3 of this chapter elaborately. It is predicted that AV138 resin is found to be more suitable for joining the Al sandwich panels. The selected adhesives are applied over the surfaces to be joined after proper cleaning of surfaces. Thus the various joint configurations are prepared.
4.3.3  Curing

It is very much essential for getting sound joint. Usually the joints are cured at room temperature. The curing time mostly depends on the hardener used along with the adhesives. In the present case the HV998 hardener is used and it requires a curing time of 6 hrs. The curing time was optimized by testing different samples with varying the curing time from 4 hrs to 10 hrs in steps of 1hr. In each category two samples have been tested. The preparation methods of various joints are briefed in the following sub sections.

4.3.4  Configurations of Butt Joint

The butt joint preparation methods using Al honeycomb sandwich panels are briefed in this section. In order to predict the best joining method that yield high compressive strength, shear strength, flexural stiffness, core shear modulus and stiffness, different joints are required to be prepared and tested for the above characteristics. Six different butt joint Configurations of type ‘A’ to ‘F’ are prepared with and without inserts. Each configuration is different in terms of the edging and inserts that are briefed below.

1. **Configuration ‘A’**: The two panels are kept face to face and the direct abutment of faying faces with resin to form the joint.

2. **Configuration ‘B’**: The panels faying edges are compressed at top and bottom to the thickness equal to the face sheet thickness and using the inserts of flat shape at both top and bottom with adhesives joints are formed.

3. **Configuration ‘C’**: The faying edges of the panels are dressed with C-shaped aluminum channels and abutments of channel faces are achieved using resin to form a joint.
4. **Configuration ‘D’**: The faying edge of the panels are cut transversely and compressed to half of its thickness and overlapping each other with the application of resins without inserts to form a joint.

5. **Configuration ‘E’**: The faying edges are compressed to half of its thickness without transverse cut and applying resin to form a joint.

6. **Configuration ‘F’**: It is formed between two panels without any edging operations and inserting Al sheet with the application of adhesives.

The detailed preparation of the above joints is briefed in subsequent sections with the edge preparations, details and shapes of inserts and application of adhesives. The drawing of each configuration with the photographic view is presented in Section 4.5. In similar way, the joint configurations of tee joints are illustrated in next sub section.

### 4.3.5 Configurations of Tee Joints

The tee joint is also widely used in fabrication sites and it is expected to take the stiffness to withstand the transverse loads. In order to analyze the characteristics of tee joints, it has been prepared with or without inserts as in the case of butt joint. The edge preparations are carried out prior to joining process. The adhesives are applied allowed to cure to yield maximum strength. Three different edge configurations are formed and used for testing.

1. **Configuration ‘G’**: The faying faces of the panels are direct abutment with resin without insert and edge preparation to form a joint.
2. **Configuration ‘II’**: The faying face of the vertical member is prepared to take up an insert (C shape) and the other horizontal member is used as it is and adhesive is applied to form the joint.

3. **Configuration ‘I’**: The edges of faying faces of two horizontal members are edge prepared and C shaped inserts are placed.

Similar to butt joints, the drawing with details of joint of each configuration and its photographic view is presented in section 4.5. The inserts and the edge preparations of butt and tee joints along with the fixtures used are detailed in the next section.

### 4.4 INSERTS AND SHAPING OF EDGES

Inserts of flat and C-shapes are used in forming both butt and tee joints of Type B, C, F, H and I. The material of the inserts are chosen as same grade as that of the panel material. The inserts are prepared using the shearing and bending machines. The dimensions of the inserts are selected so that after using the same surface thickness is not increased and maintain the flatness. The shapes of the inserts used for various types of configurations are illustrated in Figure 4.3 (a) and (b).

![Figure 4.3 (a) Flat insert](image1.png)  ![Figure 4.3 (b) C-shaped insert](image2.png)
The shapes of the insert as indicated in Figure 4.3 (a) are selected so that the honeycomb core is properly secured and supported. This type of insert in vertical position provides additional shear resistance and in the horizontal position provides higher bond area. The shapes of the insert as indicated in Figure 4.3 (b) is selected so that the honeycomb core gets fully covered and the aluminum sheet of the channel section gets directly bonded to the counterpart and enhances the bond strength.

The edges of the faying end of the panels are carefully shaped to obtain the joints of various configurations. The edges are compressed using a flexural testing machine with the aid of fixtures to a specified length and depth so as to accommodate the inserts. The digital flexural testing machine that is used has the capability of moving its ram to the accuracy of 0.01mm. The specification of the machine is presented in the Chapter 5 in section 5.2.

The fixture used for edging operation is designed and fabricated. The material for the fixture is selected as mild steel as the working material as aluminum. The surfaces are machined with CNC machines to the accuracy of 0.1mm. The fixture has the facility to hold the faying end of the panel to a specified length and the compressive force is applied using the ram over the flat platen. The clearance between the platen and the fixture is maintained as less than 1mm. The detailed dimensions of the fixture, its exploded view and its photographic view with and without specimen are given in the Figure 4.4 (a), (b) and (c).
Figure 4.4 (a) Fixture design for edging of honeycomb panel

Figure 4.4 (b) Fixture for edging of honeycomb panel

Figure 4.4(c) Edging of honeycomb panel
The edges of the faying end of the panel are prepared for different joints in the following ways. The configuration ‘B’ needs the top and bottom sides of the edges to be compressed to 2 mm. It is carried out after cutting the faying end at the length equal to half of its panel thickness. Thus the joint width will be equal to the panel thickness after completion of joint that are shown in the Figure 4.7. The type ‘C’ configuration also needs end preparation similar to type ‘B’ and instead of flat inserts; C-shaped inserts are used.

The type ‘D’ configuration requires the preparation edge by cutting the face sheet and core to the depth and length equal to half of the panel thickness. Further, it is compressed using flexural testing machine with the aid of fixtures. The detailed dimension of the faying end with its photographic view is presented in Figure 4.9. The edge preparation of type ‘E’ configuration is also similar to type ‘D’ but the compression is carried out without cutting the faying end thus it can accommodate larger quantity of adhesives that is expected to have better bonding and more strength with reference to Figure 4.5.

Figure 4.5 Honeycomb sandwich panel sample after edging
The edges thus formed are used for preparation of joint of various configurations. The detailed procedure of preparation of joints is briefed in the next coming section.

4.5 FABRICATION OF BUTT AND TEE JOINTS

The various configurations are formed with AHCS panels as described in the section 4.3. The joints are formed after edging, joining and curing. During joining, the cavities are inevitable at the end of the faying panels as they are cut from honeycomb panel. It needs to be filled with polyurethane foam impregnated with AV138 resin to achieve the better bonding surfaces. In case of curing process, the joint is allowed to harden in natural atmospheric condition for 6 hrs. Further, it is transferred to the heating environment in oven and 80°C is maintained for one hr. The filling of cavity and the curing procedure is adapted for all the joint configurations uniformly. The techniques involved in preparation of various configurations are briefed in this section.

The six configurations of butt joints (Configuration ‘A’ to ‘F’) and three confirmations (Configuration ‘G’ to ‘I’) have been proposed to preparation joining panels in practical usage. The joint configurations have been designed so as to enhance the bonding area there by the mechanical properties can be increased. Where ever possible the inserts are suggested to have better bonding area and to increase the stiffness of the joints. The polyurethane foam materials are suggested to fill the cavity forming during the edge preparation. The various configurations are detailed in next coming sub sections.
4.5.1 Configuration ‘A’

The faying faces of the panels are taken without edge preparation. The AV138 resin is applied at its faces to be joined. After the application of resin the two specimens are joined together and fastened using a clamp to hold the specimen in position. Then curing procedure is adapted to achieve better strength. The sketch of the configuration ‘A’ and a photographic view of the same is presented in Figures 4.6 respectively.

Figure 4.6 Butt joint – Configuration ‘A’
4.5.2 Configuration ‘B’

In this configuration, the edges of the panel are prepared and the flat insert is kept at top and bottom of the faying end. After cavity filling, the resin is applied and cured to achieve better strength. The sketch showing the details of insert, resin, shaped panel and core of the joint and its photographic view is given in Figure 4.7. It is expected to yield more strength in comparison with configuration ‘A’ as it provides more bonding area because of inserts.

Figure 4.7 Butt joint – Configuration ‘B’
4.5.3 Configuration ‘C’

In configuration ‘C’, the edges of the panel are shaped to accommodate the C-shaped insert on both the ends to be jointed after filling the cavity. The inserts increases the area to be joined and resin is applied over the surfaces and curing process is carried out. It is expected to yield better strength characteristics than both configuration ‘A’ and ‘B’ as it provides better surface area for bonding compared to other configuration mentioned above. The sketches showing the various elements of joint and its photographic view are shown in the Figure 4.8.

![Figure 4.8 Butt joint – Configuration ‘C’](image-url)
4.5.4 Configuration ‘D’

The configuration ‘D’ is achieved by preparing the panel edges by cutting them in transverse direction and compressing without inserts. The faying ends are placed one over another after filling the cavity the resin is applied and curing process is carried out. It resembles like half lap joint and is expected to have more strength and smooth surface after joining. The sketch showing the fine details of the elements and the photographic view of the same is shown in the Figure 4.9.

Figure 4.9 Butt joint – Configuration ‘D’
4.5.5 Configuration ‘E’

The configuration ‘E’ differs from ‘D’ in the way it does not require transverse cut and inserts at the faying ends. It requires edging of the faying ends to be compressed to half of its depth, filling of cavity, application of resin and curing to achieve strength of the joint. The requirement of resin is more as it fills the top and bottom portion of joint surface of the faying end after compression. Sketches showing the details of the joint and its photographic view are shown in the Figure 4.10.

Figure 4.10 Butt joint — Configuration ‘E’
4.5.6 Configuration ‘F’

The joint configuration ‘F’ does not require edge preparation and needs one insert of aluminum sheet to cover the entire portion of the end of the panel. It requires filling of cavity, application of resin and curing process. It is expected to yield better compressive strength. The details pertaining to the joint and its photographic view are shown in the Figure 4.11.
4.5.7 Configuration ‘G’

The configuration ‘G’ is designed as tee joint, it does not require edge preparations and inserts. It requires filling of cavity in vertical member and needs application of resin and curing process. It is expected to have good stiffness and moderate toughness properties. The details regarding the joint and its photographic view are presented in Figure 4.12.

Figure 4.12 Tee joint – Configuration ‘G’
4.5.8 Configuration ‘H’

The configuration ‘H’ needs the preparation of the faying end of the panel and C-shaped inserts fitted on the vertical member. It increases the surface area of bonding to some extend and needs the application resin and curing process to achieve better strength. It is expected to have more stiffness and toughness in comparison with configuration ‘G’. The joint details with sketch and the photographic view are given in Figure 4.13.

Figure 4.13 Tee joint – Configuration ‘H’
4.5.9 Configuration ‘I’

It is configured in view of enhancing the stiffness and toughness further when compared to previous two joints. Two C-shaped inserts are employed instead of one on two horizontal members and the vertical members are placed in between them to achieve better stiffness. The joint requires the application of resin and curing process to achieve better strength. The details of the joints and the photographic views are shown in the Figure 4.14.

Figure 4.14 Schematic of tee joint – Configuration 'I'
The above configurations are formed using Al honeycomb sandwich panel and it needs to be tested for its strength. It is required to evaluate the above configuration and based on its strength criteria it is possible to suggest better joint for practical use in the actual construction site.

4.6 STUDY OF VARIOUS JOINTS

The study of various configurations pertaining to butt and tee joints are to be carried out for evaluation of thickness of adhesives, bonding surfaces, filling of cavity and surface properties before subjected to experimental Investigation. The manual examination has been carried out on specimen about the thickness of adhesives and bonding surfaces and filling of cavity and curing etc., and then the samples subjected to experimental testing. In order to predict the above features of the joint a systematic study on macroscopic point view is performed. The investigation of the joints is performed in various stages as given below.

- Stage I: The joint specimen is carefully sliced transversely so as to expose the thickness of the adhesives and its core and face sheets with cavity filling.

- Stage II: The cross section of the specimen is metallographically prepared with Silicon Carbide (SiC) emery paper of various grades and further polishing in the vicinity of Diamond paste to remove the burr present in the sectioned area. The samples are etched with 10% hydrofluoric acid and dried.

- Stage III: The samples are viewed with the aid of stereo microscope and light optical microscope to predict the thickness of the core and face sheets with adhesives. The values are
recorded for various specimen of each category and the average value is taken as reference. The view is also photographed.

The macroscopic investigation is performed for the samples of all the joint configurations of ‘A’ to ‘I’ along with the parent material (Al Honeycomb sandwich panel) for comparison. The finding of the investigation with regard to various joint configurations with schematic diagram and photographic views are presented in the next subsections.

4.6.1 Macroscopic Investigation of Joints

The configuration ‘A’ to ‘I’ along with parent material is investigated at three stages detailed in previous sections. The investigations pertaining to each of the joint along with the schematic diagram and the photographic views are given in sequential way. The prediction of the various elements of the cross section of each configuration with the aid of magnified views (1X and 10X) is used to ensure the effective joining of the panels. The Figure 4.15(a) & (b) illustrates the 1X and 10X magnified view of the parent material. Whereas the Figures 4.16(a) & (b) to Figure 4.24 (a) & (b) represents the 1X and 10X magnifications of specimens corresponding to Configuration ‘A’ to ‘I’.

(a) Magnification (1X)  
(b) Magnification (10X)

Figure 4.15 Parent Material
Figure 4.16 Configuration ‘A’

(a) Magnification (1X)  
(b) Magnification (10X)

Figure 4.17 Configuration ‘B’

(a) Magnification (1X)  
(b) Magnification (10X)

Figure 4.18 Configuration ‘C’

(a) Magnification (1X)  
(b) Magnification (10X)
Figure 4.19 Configuration ‘D’

(a) Magnification (1X) 
(b) Magnification (10X)

Figure 4.20 Configuration ‘E’

(a) Magnification (1X) 
(b) Magnification (10X)

Figure 4.21 Configuration ‘F’

(a) Magnification (1X) 
(b) Magnification (10X)
Figure 4.22 Configuration ‘G’

(a) Magnification (1X)  (b) Magnification (10X)

Figure 4.23 Configuration ‘H’

(a) Magnification (1X)  (b) Magnification (10X)

Figure 4.24 Configuration ‘I’

(a) Magnification (1X)  (b) Magnification (10X)
Following are the inferences from macro-section examinations presented in Figures 4.15 to 4.24:

- It can be seen from the macro-section that the use of polyurethane foam to absorb resin and also to support the resin during curing has led to sound butt joints.

- The vertical insert (Figure 4.2.1) provided at the joint has facilitated to retain the resin and yielded better strength to the joint.

- The Edging of the sandwich panel (Figure 4.19, 4.20) by compression loading has facilitated additional bond area.

- Aluminum C-channel section (Figure 4.18, 4.23 and 4.24) has facilitated extra area for the application resin leading sound joints.

4.7 SUMMARY

In this chapter, the focus is with respect the choice of thermo-set resins for the fabrication of butt and tee joints. The best resin for the preparation of joints is identified. It has been found that resin AV 138 has highest shear strength and it exhibits very good bonding with Al block. Hence this resin has been used for the fabrication of joints of sandwich panels. The experimental procedures and analysis of results using the identified resin is briefed in the forthcoming chapters.