Abstract

The purpose of this report is to outline the path and methods used to design a specimen fixture for the testing and analysis of fiber reinforced composites subjected to impact loading. This design is done in support of the California Polytechnic State University in San Luis Obispo Structures and Composites Laboratory. The design request was made at the request of Dr. Eltahry Elghandour to support the graduate students Kodi A. Rider and Y. Vanessa Wood in their master’s degree thesis projects.

The design request involved the design of a specimen fixture compatible with the existing impact apparatus located in the laboratory. The apparatus is an Instron Dynatup 8250 HV Drop Weight Impact Testor. The design must adhere to the requirements of the testing standard ASTM D 7136 except as noted by Dr. Elghandour where the testing fixture was to be operated by a pneumatic clamping system.

The specimen fixture was designed to be made of 6061-T6 aluminum alloy. Finite element analysis was used to determine the maximum impact load that the specimen fixture could safely withstand. According to the operator’s manual of the impact tester, the maximum impact load that the specimen fixture would need to withstand was 100 lb at a velocity of 6 m/s, which translates to a force of about 31000 lb. After structural analysis using SolidWorks Simulation FEA, the highest impact load the specimen fixture design could withstand was 45000 lb, at which point plastic deformation would begin to occur at the welds of the central core tubular support assembly. This load far exceeds the load as specified in the operator’s manual.

The specimen fixture was then fabricated and assembled by myself and installed into the Dynatup 8250 apparatus with the aid of Kodi A. Rider. The fixture was then tested using a ½ inch thick foam and carbon fiber sandwich plate at maximum velocity and showed no signs of plastic deformation or fracture failure.
Acknowledgements

I wish to thank Dr. Eltahry Elghandour for being my senior project advisor and for choosing me to design and fabricate this piece of equipment for his laboratory. I sincerely hope that I made an asset and viable teaching tool for his future students. I also wish to thank Kodi A. Rider for his help in the procurement of parts and installation of the fixture assembly into the apparatus.

I wish to thank my father, Daniel J. Barath, in the assistance of the fabrication of specimen fixture components. Without you, none of this would have been possible. I would also wish to thank Peter and Christina Serrano, Fiodor Filipov, Brinton Jones, and John K. Shaw who provided the moral support that kept this project moving.

I also wish to thank the people of Martinek Manufacturing, who donated their time and efforts into the welding of the aluminum core support structure.
Table of Contents

Abstract ........................................................................................................................................................................... i
Acknowledgement ............................................................................................................................................................. ii
Table of Contents ........................................................................................................................................................... iii
List of Tables ................................................................................................................................................................. iv
List of Figures ............................................................................................................................................................... v
List of Equations ........................................................................................................................................................... vi
Nomenclature .............................................................................................................................................................. vii

1. Introduction .......................................................................................................................................................... 1
   1.1. Impact Resistance ........................................................................................................................................ 1
   1.2. Impact Resistance Testing Methods .......................................................................................................... 1
   1.3. Testing Standards ...................................................................................................................................... 3

2. Customer Design Request .................................................................................................................................... 4

3. Flowdown Requirements ...................................................................................................................................... 5
   3.1. Compatibility With theInstron Dynatup 8250 Drop Weight Impact Tester ............................................. 5
   3.2. Compliance to ASTM D 7136 Standard Test Method for Measuring the Damage Resistance of a Fiber-
       Reinforced Polymer Matrix Composite to a Drop-Weight Impact Event .............................................. 6
   3.3. Specimen Fixture Structural Matrix ......................................................................................................... 7
   3.4. Pneumatically Actuated Clamping Systems ............................................................................................... 8

4. Fixture Design ....................................................................................................................................................... 9
   4.1. Design Considerations ................................................................................................................................. 9
   4.2. Specimen Fixture Component Design ....................................................................................................... 14
       4.2.1. Baseplate ......................................................................................................................................... 14
       4.2.2. Central Core Support ....................................................................................................................... 15
       4.2.3. Specimen Tabletop ........................................................................................................................... 17
       4.2.4. Clamp .......................................................................................................................................... 18
       4.2.5. Pneumatic Cylinder ......................................................................................................................... 19
   4.3. Assembled Specimen Fixture ....................................................................................................................... 19

5. Structural Analysis .............................................................................................................................................. 22
   5.1. Solid Model .............................................................................................................................................. 22
   5.2. Force and Boundary Conditions ............................................................................................................. 22
   5.3. Element Type and Mesh ........................................................................................................................... 24
   5.4. Results ..................................................................................................................................................... 25

6. Final Prototype ..................................................................................................................................................... 29

7. Conclusion ........................................................................................................................................................... 32

References ................................................................................................................................................................. 33

Appendix ................................................................................................................................................................... 34
   Drawing Number A10001: Specimen Fixture Assembly .................................................................................. 35
   Drawing Number A10002: Baseplate .................................................................................................................. 36
   Drawing Number A10003: Core Support Assembly .......................................................................................... 37
   Drawing Number A10004: Specimen Tabletop ............................................................................................... 40
   Drawing Number A10005: Clamp Plate ............................................................................................................ 41
List of Tables

Table 4.1 ...................................................................................................................................................................... 13
List of Figures

Figure 1.1: Charpy impact resistance test apparatus ................................................................. 2
Figure 1.2: Difference between Charpy and Izod impact resistance tests .............................. 2
Figure 1.3: Typical drop weight impact resistance test apparatus .............................................. 3
Figure 3.1: Instron Dynatup 8250 HV Drop Weight Impact Tester ........................................ 5
Figure 3.2: Floor plan of the Instron Dynatup 8250 HV Drop Weight Impact Tester Apparatus .................................................................................................................. 6
Figure 3.3: Specimen configuration as specified by the ASTM D 7136 testing standard ........ 7
Figure 3.4: ASTM D 3763 clamping method ........................................................................ 8
Figure 3.5: ASTM D 7136 clamping method ........................................................................ 8
Figure 4.1: Layout of baseplate, pneumatic cylinders, and material specimen .......................... 11
Figure 4.2: Bimba 173-DX pneumatic cylinder ...................................................................... 11
Figure 4.3: Baseplate solid model .......................................................................................... 14
Figure 4.4: Core support flange ............................................................................................. 15
Figure 4.5: Central core support tube .................................................................................... 16
Figure 4.6: Central core support welded assembly ................................................................. 17
Figure 4.7: Specimen table top. Bottom surface shown .......................................................... 17
Figure 4.8: Clamp ................................................................................................................... 18
Figure 4.9: Pneumatic Cylinder ............................................................................................. 19
Figure 4.10: Assembled specimen fixture shown with clamp extended. Pneumatic air fittings and 3/8-16 socket head cap screws omitted for clarity ................................................................. 20
Figure 4.11: Side view of the specimen fixture assembly .......................................................... 21
Figure 5.1: Assembly used for FEA model ........................................................................... 22
Figure 5.2: Bottom surface of baseplate showing boundary condition constraints on the mounting holes and on the entire bottom surface ................................................................. 23
Figure 5.3: Impact reaction force distribution over contact surface of material specimen and specimen tabletop ........................................................................................................ 24
Figure 5.4: Tetrahedral parabolic element used in this finite element model .......................... 24
Figure 5.5: FEA model mesh. Note high element density areas at the corners of the core support tube, weld bead corners, and at the corne of the cutout on the specimen tabletop ........................................ 25
Figure 5.6: Von Mises stress plot for model loaded at 35000 lbf. Highest loads occur at the corners of the bottom weld bead and at the corners of the cutout on the specimen tabletop ........................................ 26
Figure 5.7: Displacement plot for model loaded at 35000 lbf. Plot also shows deformed shape of model ................................................................. 26
Figure 5.8: Factor of safety plot for model loaded at 35000 lbf ................................................. 27
Figure 5.9: Factor of safety plot for model loaded to 45000 lbf ................................................ 28
Figure 6.1: Final prototype assembly before installation into the Dynatup 8250 apparatus ................................................................................................................................. 29
Figure 6.2: Fixture apparatus as installed into the Dynatup 8250 apparatus ............................ 29
Figure 6.3: Dynatup 8250 control panel ................................................................................ 30
Figure 6.4: Air flow diagram ............................................................................................... 31
List of Equations

Equation (4.1): Expression for upper piston surface area ................................................................. 10
Equation (4.2): Expression for the force multiplier of all four cylinders ........................................... 10
Equation (4.3): Expression for clamping force .................................................................................. 10
Equation (4.4): Kinematic equation for velocity ............................................................................... 12
Equation (4.5): Expression for impact deceleration ....................................................................... 13
Equation (4.6): Newton’s Second Law to determine impact force ....................................................... 13
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a$</td>
<td>acceleration/deceleration</td>
<td>(ft/s²)</td>
</tr>
<tr>
<td>$A$</td>
<td>area</td>
<td>(in²)</td>
</tr>
<tr>
<td>$A_t$</td>
<td>total piston face area</td>
<td>(in²)</td>
</tr>
<tr>
<td>$d_p$</td>
<td>piston diameter</td>
<td>(in)</td>
</tr>
<tr>
<td>$d_s$</td>
<td>piston shaft diameter</td>
<td>(in)</td>
</tr>
<tr>
<td>$F_c$</td>
<td>clamping force</td>
<td>(lb)</td>
</tr>
<tr>
<td>$F_i$</td>
<td>impact force</td>
<td>(lb)</td>
</tr>
<tr>
<td>$m$</td>
<td>impactor mass</td>
<td>(lb)</td>
</tr>
<tr>
<td>$P_c$</td>
<td>clamping pressure</td>
<td>(psi)</td>
</tr>
<tr>
<td>$v_0$</td>
<td>impact velocity</td>
<td>(ft/s)</td>
</tr>
</tbody>
</table>
1. **Introduction**

Fiber reinforced composite materials have revolutionized the aerospace and automobile industries due to their low density and high strength. These materials have revolutionized these industries by allowing designers to use lightweight, high strength materials that increase efficiency and performance of vehicles. However, fiber reinforced materials are relatively new to engineering and the properties of these materials are still being developed. These properties are highly dependent on the composition and configuration of the fibers within the composite. Therefore, when new developments are made in composition and configuration, the mechanical properties of the composite material must be tested and validated for use within the industry. Testing methods must also be developed which are appropriate to the material and mechanical property being tested. For example, the tensile behavior of a material is tested by placing specimens of a material under tension and determining the stress/strain behavior. With these tests, engineers and scientists can have a reliable basis on which to produce designs, analyze those designs, and turn those designs into reliable and safe products for use within the public and private domain.

1.1. **Impact Resistance**

Impact resistance is an extremely important mechanical property measuring fracture toughness that must be determined and quantified for any type of structural material\(^1\). For example, a spacecraft must be designed to withstand impacts from micrometeorites and other space debris that it may encounter. The structure must be able to withstand these impacts in such a way to protect the internal payload from catastrophic damage due to impact and still remain structurally sound. This is especially important if the spacecraft has a human payload. Another example arises during the manufacture of spacecraft and aircraft vehicles. During manufacture, a technician may drop a tool onto a cured fiber reinforced surface causing damages to the material such as delamination of the fiber plies and/or tearing of the fibers themselves. Other impact event examples include bird strike to an aircraft structure during flight. In the automotive industry, these examples include impacts with other vehicles and debris thrown up from the road. Drop impact event testing addresses these potential events and quantifies them for design and analysis.

1.2. **Impact Resistance Testing Methods**

There are many types of impact testing methods. For example, one method is the Charpy Impact Test. In this testing method a pendulum hammer swings into a material specimen. The impact energy is
determined by measuring the distance the hammer travels from fracturing the specimen until rest. This distance gives the impact energy absorbed during fracture of the material. Therefore a “V” notch of known configuration is cut into the material specimen to facilitate fracture of the specimen. A Charpy Impact Resistance Test Apparatus is shown in figure 1.1. Note the pendulum hammer on the left of the apparatus. Also there is a scale used to measure the swing angle after impact and fracture of the material specimen located in on the right of the apparatus. The material specimen is held as a simply supported beam and the hammer strikes the middle of the beam between the supports of the beam. Another method is the Izod Impact Test. This test is similar to the Charpy method except that the material specimen is held as a cantilever beam. Figure 1.2 shows the difference between the Charpy and Izod methods. Note that the Charpy and Izod test methods both use beam type material specimens[2].

The third type of test is the Drop Weight Impact Resistance Test. With the drop weight impact resistance test, a weight is dropped from a known height and allowed to accelerate under the force of gravity. The weight has a similar hammer on the striking end of it to that of the Charpy and Izod methods. The hammer comes down and strikes the material specimen causing some type of failure, whether it be fracture, cracking, plastic deformation, or purely elastic deformation. In the case of fiber reinforced
composite materials, delamination and/or tearing of fibers can occur as material failures. With the drop weight method, the weight is guided to the target material specimen by sliding through a tube or by sliding down guide rails. The acceleration of the impact weight can also be assisted by compressed air or springs to increase impact velocities above that with gravity alone. A typical drop weight apparatus is shown in figure 1.3. With this apparatus, the impact weight is drawn up to its release height by a chain where it is then released. Note how the apparatus has two guiderails on either side of the impact weight. The specimen is housed in the yellow box. The impact weight can have an accelerometer or load cell attached to it so that a time history of the impact force can be determined. This is important so that the behavior of the material during impact can be assessed.

1.3. Testing Standards

Depending on the type of material being tested, the method of testing, or the configuration of the material being tested, ASTM International has produced standards governing the method and analysis for many types of impact resistance tests. There are standards for both Carpy and Izod tests for metallic\textsuperscript{[2]} and plastic materials\textsuperscript{[3][4]}. For the case of drop weight impact testing there are standards plastics\textsuperscript{[5]}, and fiber reinforced composites\textsuperscript{[6]}. With regard to the fiber reinforced composite materials, ASTM D7136 is of particular interest. This standard governs the configuration of the test sample, the proper type of impact device to use, and the proper configuration of clamp to hold the test specimen.
2. **Customer Design Request**

The customer, the Cal Poly Aerospace Structures and Composites Laboratory, has requested the design, fabrication, and installation of a test fixture with which to hold a composite material specimen for drop weight impact resistance testing. The customer has placed the following requirements on the fixture:

- The fixture must be compatible with the Instron Dynatup 8250 Drop Weight Impact Tester located within the lab.
- The fixture must conform to the requirements of ASTM D 7136 Standard Test Method for Measuring the Damage of a Fiber-Reinforced Polymer Matrix Composite to a Drop-Weight Impact Event.
- The support structure must be made from 6061 aluminum.
- The fixture must use pneumatic cylinder with which to clamp the specimen to the fixture with a clamping device similar to that called out in ASTM D 3763 section 6.1.1.
3. Flowdown Requirements

Each of the requirements laid out by the customer places its own set of flowdown requirements on the design of the fixture assembly. These flowdown requirements place restrictions on the configuration, materials, and method of the design of the fixture. Each customer requirement is addressed below.

3.1. Compatibility with the Instron Dynatup 8250 Drop Weight Impact Tester

The Dynatup 8250 apparatus is shown in figure 3.1. The model in the structures and composites laboratory has the high velocity option included. This means that this particular model has a pneumatic assist that can accelerate the impact device faster than with just gravitational acceleration if needed. This included option requires that the specimen fixture be designed to handle larger impact forces.

Since the fixture must fit with in the tester, the fixture must not interfere with the working components of the tester. Therefore, the tester must fit between the slide rails of the apparatus and must use the allowed mounting points of the tester. The allowable workspace inside the tester is shown in figure 3.2. The available workspace inside the testing apparatus is a 14 inch square indicated in the figure by the shaded blue area. However, the space is actually limited by the two vertical guide rails. The diameter of each of the guide rails is .75 inch. The guide rails are indicated in the figure by green. Therefore, the actual area allowed for the specimen fixture to sit is a six inch wide strip in between the guide rails. The impact location is located in the center of the 14 inch square between the guide rails and is indicated in the figure by red.

Figure 3.1: Instron Dynatup 8250 HV Drop Weight Impact Tester
So the clamping site is accessible to an operator, the fixture must have a certain height so that the specimen can be easily installed and removed after testing. The floor of the workspace inside the Dynatup 8250 is located 6 inches below the bottom of the door shown in figure 3.1. Therefore the specimen must be located at a height of 6 inches or higher.


The ASTM D 7136 standard imposes many flowdown requirements which affect the design of the fixture. The flowdown requirements are stated by the applicable section in the standard.

- Section 8.2.2 of the standard requires that the specimen be a 4 inch by 6 inch rectangle as shown in figure 3.3. Note the location of the impact is in the center of the rectangular specimen.
Section 7.2 of the standard requires that the exposed specimen surface underneath the specimen be a 3 inch by 5 inch rectangular area centered with respect to the specimen.

Section 7.2 of the standard requires that the specimen be clamped to the surface of the support structure by a minimum of 200 lbf.

Section 7.2 of the standard requires that the clamping apparatus contact the upper surface of the specimen using neoprene rubber 70-80 shore A.

Section 7.2 of the standard requires that guide pins be placed on the support fixture in order to locate the specimen centrally over the 3 inch by 5 inch exposed area underneath the specimen.

3.3. Specimen Fixture Structural Material

The material requirement imposed by the customer states that the main structure shall be 6061 aluminum. For maximum rigidity of the structure, all components of the fixture structure will be of the T6 temper.

Figure 3.3: Specimen configuration as specified by the ASTM D 7136 testing standard.
3.4. Pneumatically Actuated Clamping System

This requirement imposes that pneumatic cylinders be used to actuate the clamping system of the fixture. The customer has specified a similar clamping method to that described in ASTM D 3763 Standard Test Method for High Speed Puncture Properties of Plastics Using Load and Displacement Sensors. Section 6.1.1 of this standard specifies that two parallel rigid plates be used to clamp the specimen to the fixture\textsuperscript{[5]}. Figure 3.4 shows an example of the ASTM D 3763 clamping method.

This requirement conflicts with the method stated in ASTM D 7136 section 7.2 where the specimen is to be clamped using toggle clamps, one at each corner of the specimen with a total clamping force of 200 lb. Figure 3.5 shows an example of the ASTM D 7136 clamping method. This conflict was discussed with the customer and the resolution was that the method of ASTM D 3763 section 6.1.1 shall take precedence over that of ASTM D 7136 but the specimen configuration of ASTM D 7136 sections 7.2 and 8.2.2 shall take precedence over ASTM D 3763 section 7.1. This means that two parallel rigid plates will be pneumatically actuated to hold down the 4 inch by 6 inch rectangular specimen and that the plates will have the 3 inch by 5 inch cutouts as specified by ASTM D 7136. The clamping system shall have a minimum clamping force of 200 lb\textsuperscript{[6]}.
4. Fixture Design

The main requirements that drive the design of the specimen fixture are to be compatible with the Dynatup 8250 apparatus, use a pneumatic clamp, and the specimen configuration as shown in figure 3.3.

- The requirement to be compatible with the Dynatup 8250 apparatus drives the overall dimensions. The length must be shorter than 14 inches. The width must be shorter than 6 inches to fit between the guide rails. The specimen must sit at a height of 6 inches or higher. All components of the specimen fixture must fit within this volume.
- Next, the pneumatic cylinders must produce a clamping force of at least 200 lb$_f$.
- The fixture must hold the 4 inch by six inch test specimen.

These are the three main driving requirements that drive the design of the specimen fixture. From these three requirements initial design considerations can be made.

4.1. Design Considerations

Beginning with the floor plan of the internal workspace of the Dynatup 8250 apparatus as shown in figure 3.2, the first component of the specimen fixture is considered: the fixture baseplate. The fixture baseplate will have the task of mounting to the Dynatup 8250 apparatus, hold the pneumatic cylinders, and serve as the main foundation of the fixture. Since the guide rails drive the width of fixture, care must be taken so that no part of the fixture makes contact with the guide rails during operation. Also it would be preferable that the fixture can be installed into the Dynatup 8250 apparatus with minimal or no assembly to facilitate installation taking place inside the apparatus enclosure. Therefore, all components must fit inside the 6 inch width between the guide rails with some clearance. A .125 inch clearance on either side of the fixture will mitigate the risk of contact between the guiderails and fixture and facilitate easy installation into the apparatus. This changes the available width of the workspace to 5.75 inches centered about the impact location. This width will contain the specimen 4 inch by 6 inch configuration.

Next the pneumatic cylinders for the clamping system can be considered. The requirement is that the clamp holds the specimen with a minimum clamping force of 200 lb$_f$. From the Dynatup 8250 user’s manual, the control system is capable of supplying a maximum air pressure of 95 psi. Therefore, the total piston face area required to produce the minimum clamping force if 200 lb$_f$ is 2.11 in$^2$. Also, given the rectangular shape of the specimen configuration, four pneumatic cylinders, one placed at each corner of
the specimen, will be used to produce the total clamping force. Therefore, the minimum piston face area for each cylinder is \(0.53 \text{ in}^2\). However, it would be preferable to control the clamping force so that a smaller force could be used with delicate specimens with small impact loads and a larger clamping force could be used for large impact loads. 1.5 inch diameter bore cylinders were chosen to act as the clamp actuators. After careful research, the Bimba model 173-DX was chosen. The 173-DX is a double acting cylinder with a stroke of 3 inches. This means that there are two inlets for air pressure on the cylinder, one on each side of the piston allowing the piston to be actuated in both directions of motion. This will allow the Dynatup 8250 control to actuate both closing and opening of the clamp. The inside diameter of the cylinder is 1.5 inch and the shaft diameter is \(\frac{7}{16}\) inch. Then the force multiplier can be calculated by determining the area of the upper face of the piston. This is the side of the piston from which the shaft extends out of the cylinder to the clamping plate. Therefore the area of the upper side of the piston is then calculated from

\[
A = \frac{\pi}{4} (d_p^2 - d_s^2)
\]

where \(A\) is the upper piston face area, \(d_p\) is the diameter of the piston, and \(d_s\) is the diameter of the shaft. For the four cylinders the total area is then given by

\[
A_t = 4A = \pi (d_p^2 - d_s^2)
\]

Equation (4.2) is then the force multiplier of the four pistons. The value of \(A_t\) for this system is then

\[
A_t = \pi [(1.5 \text{ in})^2 - (0.4375 \text{ in})^2] = 25.869 \text{ in}^2
\]

then the total clamping force is given by

\[
F_c = P_c A_t
\]

where \(F_c\) is the total clamping force and \(P_c\) is the pressure supplied to the pneumatic cylinders from the Dynatup 8250 control. From equation (4.3), it is determined that a supplied pressure of 31 psi is required to produce the 200 lb f clamping force. From the 95 psi maximum pressure supplied by the Dynatup 8250, the maximum clamping force is then 614 lb f. This range will be satisfactory for all impact masses and velocities.
Lastly, the specimen configuration of 4 inch by 6 inch rectangle requires that the specimen sit in the fixture with the 4 inch edge spanning the 5.75 width of the fixture and the 6 inch edge spanning the length of the fixture. Figure 4.1 shows how the baseplate, pneumatic cylinders, and material specimen are laid out in the Dynatup 8250 apparatus. Figure 4.2 shows the dimensional design of the Bimba 173-DX pneumatic pistons.

![Figure 4.1: Layout of baseplate, pneumatic cylinders, and material specimen.](image)

![Figure 4.2: Bimba 173-DX pneumatic cylinder.](image)

The central core support can now be considered. The central core support will be produced from 4 inch by 6 inch by .25 inch thickness 6061-T6 aluminum rectangular tube extrusion. This size was chosen
because it matches the specimen dimensions and its thickness was the largest commercially available. Two .5 thick flanges will be welded to either end of the rectangular tube extrusion with bolt holes allowing it to be mounted to the baseplate and to the specimen table. Since the pneumatic cylinders will fit between the baseplate and the specimen table, the central core support must be tall enough such that the cylinders will fit properly without any interference. From the design of the 173-DX cylinder, the required length is 6.63 inches. Then rounding up to the nearest standard fraction giving clearance space, the assembled height of the central core support will be 6.75 inches. ¼-20 socket head cap screws will mount the central core support to the base plate and to the specimen table.

The specimen table will be made of .75 inch thick 6061-T6 aluminum plate. It will have a 3 inch by 5 inch cutout underneath where the specimen will sit. Near each corner of the specimen, there will be a .5 inch diameter clearance holes for the shafts of the pneumatic cylinders to pass through. The thickness of the specimen table requires that the shafts be extended a length so that none stroke length of the clamp is lost. Therefore, the shafts have an extension of .37 inch to maintain the stroke length. This extension was chosen over the full thickness of the specimen table to ensure full closure of the clamp even without a specimen inside the clamp. Therefore the full stroke of the clamp becomes approximately 2.6 inches which fits within the customer preferred stroke range of 2.5 inch to 3 inch.

The upper clamp plate will then be made from .375 inch thick 6061-T6 aluminum plate. This plate will also have a 3 inch by 5 in rectangular cutout above the specimen. Through this hole is where the impactor will run to impact the specimen. It will also have 7/16-20 threaded holes at each corner of where the specimen is located for the threaded ends of the shafts of the pneumatic cylinders. The shafts will then be locked using nuts from rotation due to vibration caused by impact.

In order to produce a viable design that meets the main requirement of reliably holding a specimen for drop weight impact testing, the force imparted by the impactor to the specimen must be determined. This will be the assumed force that the fixture must endure during each impact test. To determine the assumed impact force, we begin with

\[
v = at_i + v_0
\]  

(4.4)
where \( v_0 \) is the impact velocity, \( a \) is the deceleration of the impactor mass at impact, and \( t_i \) is the impact time required to decelerate the impactor to zero. Then, setting equation (4.4) to zero and solving for the impact deceleration we have

\[
a = \frac{v_0}{t_i}
\]  

(4.5)

Then, by Newton’s Second Law, we have

\[
F_i = ma = \frac{mv_0}{t_i}
\]  

(4.6)

where \( F_i \) is the impact force and \( m \) is the impactor mass. Therefore, equation (4.6) gives us the expected impact force the fixture and specimen will see during impact. Then, this becomes the design requirement that the fixture must endure for testing with a suitable factor of safety to account for fatigue.

Table 4.1: Energy and velocity table for the Dynatup 8250 HV.

<table>
<thead>
<tr>
<th>Crosshead Weight lbs (kg)</th>
<th>Max. Drop Height in (cm)</th>
<th>Max. Freefall Velocity ft/s (m/s)</th>
<th>Max. Pneumatic Assist Velocity ft/s (m/s)</th>
<th>Max Freefall Impact Energy ft-lbf (J)</th>
<th>Max. Pneumatic Assist Impact Energy ft-lbf (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.5 (2.5)</td>
<td>46 (117)</td>
<td>15.7 (4.8)</td>
<td>44.6 (13.6)</td>
<td>21 (28.5)</td>
<td>170 (230)</td>
</tr>
<tr>
<td>10 (4.5)</td>
<td>45 (114)</td>
<td>15.5 (4.7)</td>
<td>35.8 (10.9)</td>
<td>37.3 (50.5)</td>
<td>199 (270)</td>
</tr>
<tr>
<td>25 (11.3)</td>
<td>43 (109)</td>
<td>15.2 (4.6)</td>
<td>28.1 (8.5)</td>
<td>89.6 (121.5)</td>
<td>306 (415)</td>
</tr>
<tr>
<td>50 (22.7)</td>
<td>40 (102)</td>
<td>14.6 (4.4)</td>
<td>23.4 (7.1)</td>
<td>165.5 (224)</td>
<td>425 (576)</td>
</tr>
<tr>
<td>75 (34.0)</td>
<td>40 (102)</td>
<td>14.6 (4.4)</td>
<td>20.5 (6.2)</td>
<td>248 (336)</td>
<td>489 (663)</td>
</tr>
<tr>
<td>100 (45.4)</td>
<td>40 (102)</td>
<td>14.6 (4.4)</td>
<td>19.7 (6)</td>
<td>331 (448)</td>
<td>602 (816)</td>
</tr>
</tbody>
</table>

To determine the highest impact load the highest mass will be used with its associated pneumatic assist velocity. Table 4.1 shows that the highest crosshead mass is 100 lb (45.4 kg) with an impact velocity of 19.7 ft/s (6 m/s)\(^7\). Using equation (4.6) with an assumed impact time of 2 milliseconds, we have

\[
F_i = \frac{mv_0}{t_i} = \frac{45.4 \text{ kg} \times 6 \text{ m/s}}{0.002 \text{ s}} = 136200 \text{ N} \approx 30620 \text{ lb}_f
\]

Then, the force is increased to 35000 lbf to include a margin of safety. This will guarantee that the fixture can reliably withstand the strongest impact available with the Dynatup 8250.
4.2. Specimen Fixture Component Design

Now that all of the design considerations have been made, each of the specimen fixture components can be designed.

4.2.1. Baseplate

The baseplate is the component that will mount the specimen fixture to the Dynatup 8250 apparatus. It also serves as the mounting point for the pneumatic cylinders and as the foundation of the entire assembly. Figure 4.3 shows a solid model of the baseplate.

![Baseplate solid model](image)

**Figure 4.3: Baseplate solid model.**

The baseplate is made from 6061-T6 aluminum plate. It is 5.75 inch wide by 12 inch long by .75 inch thick. As shown in figure 4.3, there are 4 counterbored holes for 3/8-16 socket head cap screws. These are the screws that will mount the baseplate to the Dynatup 8250 apparatus. The through holes are sized with a normal clearance per ASME B18.3 to allow for small alignment adjustments so that as the specimen fixture is installed into the Dynatup 8250 apparatus, the impactor can be aligned to the proper location in the center of the 4 inch by 6 inch specimen. The through holes are counterbored so that the 3/8-16 socket head cap screw heads sit below the upper surface of the base plate.
There are 12 $\frac{1}{4}$-20 threaded holes placed as shown for $\frac{1}{4}$-20 socket head cap screws so that the central core support can be mounted to the base plate. These holes are blind holes and do not go through the base plate.

There are four $\frac{49}{64}$ through holes with 1.5 inch diameter countersinks for the mounting of the pneumatic cylinders. These holes are located as shown and do not interfere with the $\frac{3}{8}$-16 socket head cap screws when the pneumatic cylinders are installed into the baseplate. The through hole diameter and counterbore design are driven by the design of the pneumatic cylinders as shown in figure 4.2. The cylinder is mounted to the baseplate using jam nuts supplied by the manufacturer. The jam nut is a $\frac{1}{2}$-16 thread with a 1.125 inch hex. Therefore, the diameter of the counterbore is chosen so that a standard 1.125 inch socket can fit into the counterbore to install and apply torque to the jam nut. The depth of the counterbore is also chosen so that the jam nut will make full contact with the threads on the pneumatic cylinder.

4.2.2. Central Core Support

The central core support is a 4 inch by 6 inch by .25 inch thickness 6061-T6 aluminum tube extrusion. There are two half inch thick 6061-T6 aluminum plates welded to each end of the extrusion to provide a place for $\frac{1}{4}$-20 socket head cap screws to mount to the base plate and to the specimen table top. The height of the central core support with the flanges welded on is 6.75 inches tall. Figures 4.4 through 4.6 show the flange, tube extrusion, and welded assembly respectively.

![Core support flange](image)

**Figure 4.4: Core support flange.**
The core support flange is shown in figure 4.4. The flange is made from 5.75 inch by 8.5 inch by .5 inch thick 6061-T6 aluminum plate. The flange has 12 holes for \( \frac{3}{4} \)-20 socket head cap screws. These holes have a close fit per ASME B18.3 to aid in the location of the central core support to the baseplate and the specimen tabletop. For the central core support welded assembly, there are two of these identical flanges welded to either end of the rectangular tube extrusion. Note the 1/8 inch deep recess. This is to locate the rectangular tube extrusion to the flange for welding. Also at either corner of the core support flange is a .905 inch radius cutout. This is to provide clearance to the pneumatic cylinders at the final assembly stage.

Figure 4.5 shows the central core support tube. This tube is made from 4 inch by 6 inch by .25 inch thick 6061-T6 aluminum tubular extrusion. The tube is 6 inches tall. When the flanges are welded to either end of the tube, the welded assembly will by a total of 6.75 inches tall.
Figure 4.6: Central core support welded assembly.

Figure 4.6 shows the final welded central core support assembly. This final height of this assembly is 6.75 inches tall to accommodate the pneumatic cylinders to fit between the upper surface of the baseplate and the lower surface of the specimen table top. The final assembly is welded together using two 3/16 fillet welds as shown.

4.2.3. Specimen Table Top

The specimen table top is the component that holds the specimen during impact. The specimen table top is made from 5.75 inches by 10 inches by .75 inch thick 6061-T6 aluminum plate. Figure 4.7 shows a solid model of the specimen table top.

Figure 4.7: Specimen table top. Bottom surface shown.
The bottom surface of the specimen table top is shown in the figure. There are 12 ¼-20 threaded holes so that the specimen table top can be mounted to the central core support. The threaded holes do not pass through to the upper surface of the table top so that neither the threaded holes nor the ¼-20 socket head cap screws interfere with the upper surface or the 4 inch by 6 inch specimen sitting on the top surface. In the center of the table top, a 3 inch by 5 inch cutout is placed as specified by the requirements of ASTM D 7136. There are also four .575 clearance holes that pass through the specimen table top so that the rods of the pneumatic cylinders can pass through to actuate the clamp above the specimen table top. There are .75 inch diameter by .05 inch deep counterbores on the bottom side of the specimen table top so that the bottom surface does not interfere with the tops of the pneumatic cylinders.

4.2.4. Clamp

The clamp is made from a 5.75 inch by 10 inch by .375 inch thick 6061-T6 aluminum plate and is shown in figure 4.8. The clamp has four 7/16-20 threaded holes to accept the rods of the pneumatic cylinders. The rods of the cylinders will be threaded through the four threaded holes and secured in place with nuts to prevent rotation of the rods due to vibration of the fixture assembly during impact testing operations. In the center of the clamp there is a 3 inch by 5 inch cutout so that the clamp plate does not interfere with the dynamic response of the specimen during impact.

Figure 4.8: Clamp
4.2.5. Pneumatic Cylinder

The pneumatic cylinder is a Bimba model 173-DXEE0.37. This is a 1.5 inch bore by three inch stroke pneumatic cylinder with a double acting piston. This means that there are two pressure ports, one to extend the rod and the other to retract the rod. When the cylinder is in its extended condition, the clamp is open. When the cylinder is in its retracted condition, the clamp is closed and applying a clamping force to the specimen. The pneumatic cylinder used for the design of the specimen fixture is shown its closed condition in figure 4.9.

![Figure 4.9: Bimba 173-DXEE.037 pneumatic cylinder. Shown in closed condition.](image)

The pneumatic cylinder used in the design has a .375 inch extension to the rod length. This extension ensures that minimal stroke length is lost in the assembly as the rod is passed through the specimen table top and threaded into the clamp. The cylinder has two ¼ inch NPT pressure ports. The pressure port near the base extends the rod and the pressure port near the rod end retracts the rod. The ¾-16 threaded base mounts to the baseplate and the 7/16-20 mounts to the clamp.

4.3. Assembled Specimen Fixture

The complete assembled specimen fixture is shown in figure 4.10. The complete fixture consists of the following components: 1 ea. baseplate, 1 ea. central core support, 1 ea. specimen table top, 1 ea.
clamp, 4 ea. Bimba 173-DXEE0.37 pneumatic cylinders, 4 ea. 7/16-20 nuts, and 24 ea. ¼-20 socket head cap screws.

The assembled fixture is mounted to the Dynatup 8250 apparatus by the mounting points for the 3/8-16 socket head cap screws as shown. These mounting points coincide with the threaded holes shown in figure 3.2. When installed into the Dynatup 8250 apparatus, the four 3/8-16 socket head cap screws are torqued to 160 in-lb to 185 in-lb. The ¼-20 socket head cap screws that hold the base plate and the specimen table top to the central core support are torqued to 40 in-lb to 50 in-lb. The 7/16-20 rod ends are threaded into the threaded holes in the clamp with minimal torque. The locking of the rod ends is done with the nuts and they are torqued to 400 in-lb to 650 in-lb.

Figure 4.11 shows the fixture clamp full extension length of 2.87 inches. This extension will then allow a 2.75 inch thick specimen to be reliably clamped within the structure. The reason that a smaller specimen thickness is allowed rather than a thickness equal to the full extension length is to ensure that the fixture clamps the specimen with the expected force as calculated using equations (4.2) and (4.3). The specimen table top upper surface is 8.25 inches from the bottom surface of the fixture assembly. This
allows the specimen table top to be located above the bottom threshold of the door to the workspace of the Dynatup 8250 apparatus.
5. **Structural Analysis**

To validate the design for manufacture of the prototype and use in the laboratory, finite element analysis of a solid model assembly was performed using Dassault Systeme’s SolidWorks Simulation which runs using COSMOSM FEA software and algorithms. This software allows finite element analysis on three dimensional structures with multiple components.

5.1. **Solid Model**

The solid model used to perform the structural analysis included the baseplate, central core support, and specimen tabletop. Since the force acts downward only on the specimen, the clamp plate and pneumatic cylinders were omitted from the model. The solid model used in this analysis is shown in figure 5.1.

![Figure 5.1: Assembly used for FEA model.](image)

5.2. **Force and Boundary Conditions**

The boundary conditions used for the model constraints were dictated by the method in which the specimen fixture is to be mounted to the Dynatup 8250 apparatus. Therefore, the four counterbored holes for the 3/8-16 socket head cap screws were constrained for all six degrees of freedom. Also, since the
bottom surface of the baseplate is supported by the bottom floor surface of the inner workspace of the apparatus, the bottom surface of the baseplate was constrained for vertical movement. Figure 5.2 shows the constraints on the baseplate.

![Figure 5.2: Bottom surface of baseplate showing boundary condition constraints on the mounting holes and on the entire bottom surface.](image)

The loading condition on the specimen fixture was dictated by the specimen geometry and its placement on the specimen tabletop. Therefore the load is placed on a rectangular strip of surface around the 3 inch by 5 inch cutout. The rectangular strip represents the specimen in contact with the specimen tabletop. The load is a vertical downward 35000 lb, static load distributed around the cutout. This load represents the reaction force of the specimen during impact as discussed in section 4.1. Figure 5.3 shows the loading of the solid model. Note the material specimen boundary is a 4 inch by 6 inch rectangle located around the cutout. All of the impact reaction force is contained within this boundary.
5.3. Element Type and Mesh

The element type used for this FEA model is a 10 node tetrahedral volumetric element. This element type uses parabolic deflection equations resulting in a linear stress element. This element was used for its higher accuracy in stress detection within the model. Figure 5.4 shows a schematic of a parabolic tetrahedral element. Note the ten nodes on the element; 4 nodes on the vertices of the tetrahedron and 6 nodes on the edges of the tetrahedron, one on the midpoint of each edge.

The mesh used for the solid model included the three components as shown in figure 5.1. The components were bonded to each other to simulate the effect of the fasteners. This was done to simplify the model for calculation resources. Figure 5.5 shows the model mesh. Note the high element density on the edges of the core support tube, at the corners of the welds, and at the corners of the cutout on the
specimen tabletop. This was done to analyze the buckling effect on the central core support and to predict with higher accuracy any potential failure areas.

5.4. Results

At 35000 lb$_f$ static load as loaded in figure 5.3, the structure holds up. The highest stress concentrations are located at the corner of the core support tube at the weld bead. At this location is where failure due to buckling will be expected. Figure 5.6 shows a plot of the stresses on the model loaded to 35000 lb$_f$. The plot has been annotated to show where the highest stress load occurs. This happens at the corners of the core support tube at the welds. The stress predicted here is 26.6 ksi giving a factor of safety at these locations of 1.5. At the corners of the cutout on the specimen tabletop the stress load is 10.2 ksi.

The maximum deflection predicted by the model is located at the midpoints of the long edge of the cutout on the specimen table. The maximum value located at these points is 5.725 thousandths of an inch. Figure 5.7 show a plot of the model displacements and show the deformed shape of the model under 35000 lb$_f$. Note how the core support tube has deformed under this load. The shape of is buckling mode is to expand outwards in its midsection. As mentioned above, the highest stress occurs at the tube corner/weld interface on the bottom flange. This is mirrored by the deflection shape. The reason why the high stress points occur here is because there is no cutout on the baseplate as there is on the specimen tabletop. Therefore, the specimen tabletop allows the core support to deform and take only compressive

![Figure 5.5: FEA model mesh. Note high element density areas at the corners of the core support tube, weld bead corners, and at the corners of the cutout on the specimen tabletop.](image-url)
Figure 5.6: Von Mises stress plot for model loaded at 35000 lbf. Highest loads occur at the corners of the bottom weld bead and at the corners of the cutout on the specimen table top.

Figure 5.7: Displacement plot for model loaded at 35000 lbf. Plot also shows deformed shape of model.
loads while the more ridged baseplate causes the support tube to hold its shape causing high stress at the connection to the baseplate. Figure 5.8 shows a factor of safety plot of the model. This plot shows the areas of concern where the stress loads approach that of the yield strength. Note that the lowest factor of safety occurs at the points on the central core support where the tube is welded to the bottom core support flange.

In an effort to determine the maximum load to cause immediate failure by permanent plastic deformation, the load on the structure was increased to 45000 lbf. Figure 5.9 shows that the points of failure are the same as indicated above with the 35000 lbf loading. Plastic deformation would begin to occur at these points and eventual crack formation to fracture would occur at these points. Fracture of the central core support tube would be the eventual location of these failures.

**Figure 5.8: Factor of safety plot for model loaded at 35000 lbf.**
Figure 5.9: Factor of safety plot for model loaded to 45000 lbf.
6. Final Prototype

The final prototype was constructed using all 6061-T6 aluminum machined as shown by the solid models shown in section 4.2. The pneumatic cylinders used were Bimba model 173-DXBWEE0.37. This model differs from the 173-DXEE0.37 in the fact that the 173-DXBWEE0.37 have protective bumpers inside the cylinder to protect the piston from slamming into the upper and lower surfaces of the inside of the cylinder. They also have wipers on the rod guide to wipe dust off of the rod as it slides back into the cylinder. These wipers protect the seals inside the rod guide from unnecessary wear.

Figure 6.1 shows the fixture assembly before installing into the Dynatup 8250 apparatus. Note the red dust covers on the pneumatic cylinders. These protect the inside of the cylinders from foreign object contamination that could cause unnecessary wear to the cylinder liners. These dust covers were removed prior to installation into the Dynatup 8250 apparatus and replaced with ¼ inch NPT to 1/8 inch i.d. tube elbow fittings. These fittings are the connection to the pneumatic cylinder from the pressure supply of the apparatus. Two fittings are required for each cylinder.

Figure 6.2 shows the fixture assembly as installed in the Dynatup 8250 apparatus. Note the fittings installed into the pneumatic cylinder as shown in the bottom of the figure. The fittings are brass and are sealed using winds of Teflon sealing tape. The pressure lines are connected to the control box of the Dynatup 8250 apparatus.

The control of the Dynatup 8250 apparatus supplies the apparatus with the air pressure to actuate the clamp fixture, release the impactor, and charge the pneumatic assist of the 8250 HV model. The control box regulates the inlet air pressure to 95 psi as mentioned in section 4.1. This is the maximum air pressure that can be used for
any of the apparatus components requiring air pressure for actuation. The control box then has a second regulator that regulates the air pressure that is supplied to the clamp system. Figure 6.3 shows the side of the control box that is located at the rear of the Dynatup 8250 apparatus. The control panel on the control box has four pressure outlets labeled “A” through “D” as shown. These outlets supply the clamp system via the air lines that run to the inside of the apparatus workspace. Outlet “A” supplies air pressure to retract the clamp and outlet “D” supplies air pressure to extend the clamp. Outlet “B” is used to operate a retraction device for the ASTM D 3763 clamping device as shown in figure 3.4. Since this feature is not needed for this clamping fixture, this outlet is capped off as shown so there is no air pressure lost during actuation of outlet “D”. Outlet “C” is not used. The control panel also has a clamp air pressure gage. This is the air pressure reading to apply to equation (4.3) to determine and set clamping pressure. The clamping air pressure is set using the knob of the air pressure regulator. 

Figure 6.3: Dynatup 8250 control panel.
The air pressure lines running from outlets “A” and “D” both run to “1 to 4” manifolds where the lines then run to the upper pressure inlets and lower pressure inlets as required. An airflow diagram is shown in figure 6.4. When the clamp closure circuit is actuated, the air pressure is supplied from outlet “A” as shown to the upper ports on the pneumatic cylinders. Any pressure below the piston is exhausted through the lower ports and out of outlet “D”. When the clamp opening circuit is actuated, air pressure is supplied from outlet “D” as shown to the lower ports on the pneumatic cylinders. Any pressure above the piston is exhausted through the upper ports and out of outlet “A”. Due to the safety feature of the Dynatup 8250 control system, the clamp open circuit is always actuated when the system is powered on. To actuate the clamp closure circuit the “ARM-CLAMP” panel button on the hand held control must be pressed and the apparatus door must be closed. The clamp closure circuit will not be active if one of these two criteria is not met.

Figure 6.4: Air flow diagram.
7. Conclusion

Section 5 shows that the model is validated for use up to the impact conditions as specified in section 4.1. The analysis of the model shows that the specimen fixture can take the maximum loads that the Dynatup 8250 HV apparatus can apply. In the analysis, the fixture was loaded to 35000 lbf static reaction force of the specimen under impact and was shown to have a factor of safety under these conditions of 1.35. When the fixture was loaded to 45000 lbf static load, this is where failure would occur.

The way in which failure would occur is by the buckling of the central core support. The location of the expected failure would be at the corners of the weld bead that joins the central core support tube to the lower central core support flange. Therefore it is expected that this is where fatigue failure would also occur. Since the amount of load required to cause immediate failure in this manner is much larger than that which could be applied by the Dynatup 8250 apparatus, fatigue failure is only a problem at the larger impactor masses.
References


Appendix

The following appendix includes the assembly and detail drawings of the specimen fixture and its related components. The first drawing, number A10001, is the assembly drawing of the specimen fixture. The next drawing, number A1002, is the detail drawing of the baseplate. The next drawing, number A10003, is a three page assembly and detail drawing of the core support assembly. The next drawing, number A10004, is a detail drawing of the specimen tabletop. The last drawing, number A10005, is a detail drawing of the clamp plate.

All drawings were made in accordance with the requirements of ASME Y14.100.