

# Adhesion Testing Fixture

by

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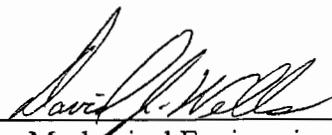
at the

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University of Cincinnati  
May 2003

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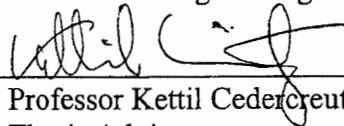
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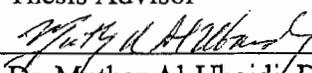
Mechanical Engineering Technology

Certified by



Professor Kjetil Cedercreutz,  
Thesis Advisor

Accepted by



Dr. Muthar Al-Ubaidi, Department Head  
Mechanical Engineering Technology

## Acknowledgements

I would like to acknowledge and thank my wife Karen, my two sons Nickolas and Jacob for their enduring patience, love and support during this lengthy process. My parents for the motivational speeches to accomplish this endeavor. My friends at school Bob Weitzel and Ron Powell keeping me from giving up, harassing me, and helping me through the tough classes. I would like to also acknowledge Steelcraft Manufacturing for the 100% funding of the project along with their support and guidance. Professor Kettil Cedercreutz, for advising the project keeping things organized. And last but not least, Dr. Muthar R. Al-Ubaidi for influencing me in his own creative methods of teaching.

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STEELCRAFT  
  
**Security & Safety**

Advisor: Professor Kettil Cedercreutz

## **Abstract**

The hollow metal door industry relies on laminated composite type construction, requiring an adhesive bond between the core material and the face sheets of the door. The peel test is a common method of measuring the strength of an adhesive and the quality of the laminating process as demonstrated by the strength of the adhesive bond. The new fixture will change the peel test to a linear pull test using a semi-automatic fixture to reduce the manual labor and cost associated with the test, while improving the reliability and repeatability of the process.

The objective is to reduce the time required by a Steelcraft lab technician to setup the test through capital equipment improvements in the Research and Product Development department at the Steelcraft Manufacturing facility in Cincinnati, Ohio. The capital equipment improvements consist of designing and building a semi-automatic pneumatic fixture that adapts to an Instron Machine. An Instron Machine utilizes electromechanical and servo-hydraulic technology to perform tensile, fatigue, structural, hardness and impact testing.

The Adhesion Testing Fixture reduces the setup time by 75%, which is a cost saving of \$5700 per year. The new testing fixture also obtained a 90% weight reduction in the sample being tested. This is because the old test used 3' x 7' sample size and the new fixture uses a 12" x 12" sample. The process is repeatable and the data accuracy is better than  $\pm 1\%$  and the fixture is compliant with ASTM C297-94.

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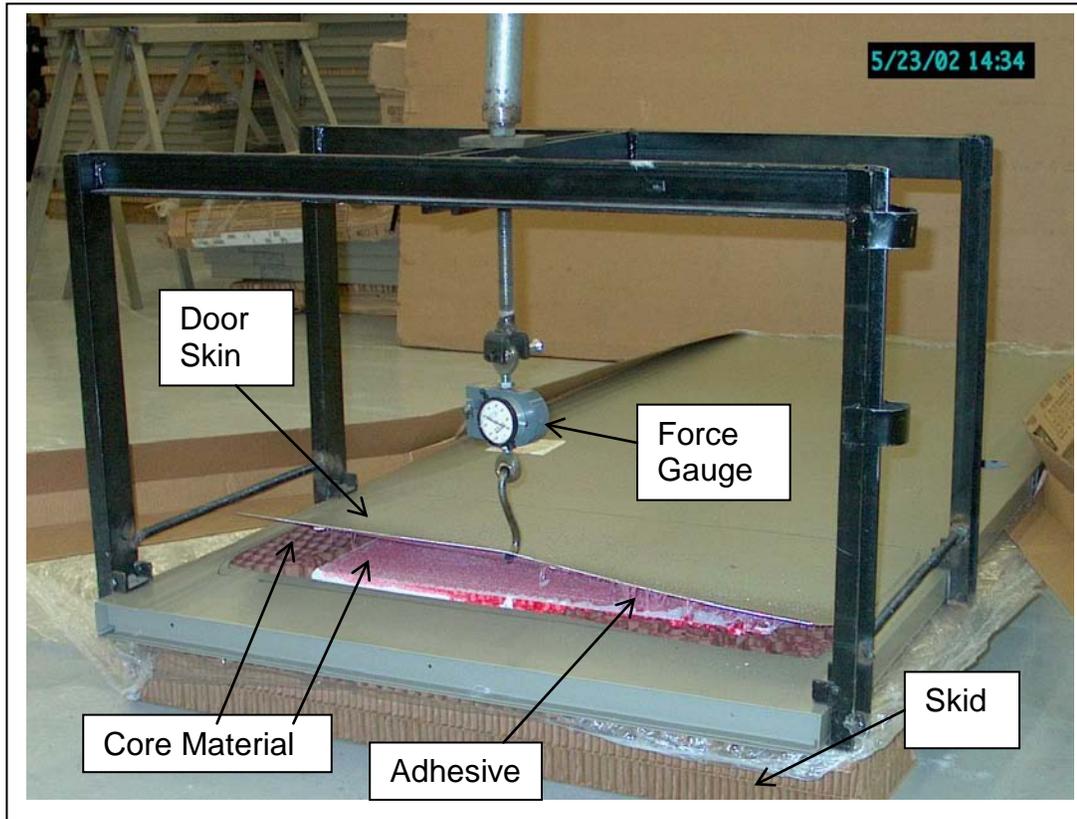
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# 1. Introduction

Steelcraft Manufacturing, a division of the Security and Safety Sector of Ingersoll-Rand, is one of the leading manufacturers of laminated-core commercial steel doors. The major components of the door consist of steel door skins, core material or adhesives that bond the core to the steel face sheets. As a means of ensuring the product performance and compliance with industry standards, Steelcraft performs quality audits on a regular basis. Approximately 780 tests are performed annually by a Steelcraft lab technician, testing the strength of the adhesive bond between the core material and the steel face sheets (see figure 1). The peel testing process, as it is currently performed, is time consuming and subject to variation. A



**Figure 1 Current Peel Testing Process**

typical test requires a lab technician approximately twelve minutes to complete.

In addition to the quality audit process, proposed engineering changes can generate demand for additional testing. The specific modifications to the door construction determine the type and number of samples required to be tested. The peel test is a mandatory requirement when proposed door modifications include changes in manufacturing processes or changes in any of the three major construction components [1].

The characteristics of the material or process changes are used to determine the amount of testing required. According to the impact of the change on the manufacturing process or one of the three major components, sample size can vary from 6 to 100, chosen from a production run of 100 consecutive doors for one test report [2]. Generally, due to the volume of the material used, new suppliers are continually being evaluated as potential replacements or second suppliers. The peel test provides Steelcraft with a valuable means to test the potential of new adhesive suppliers without compromising production schedules because the test are performed in the Research and Product Development department which is away from production.

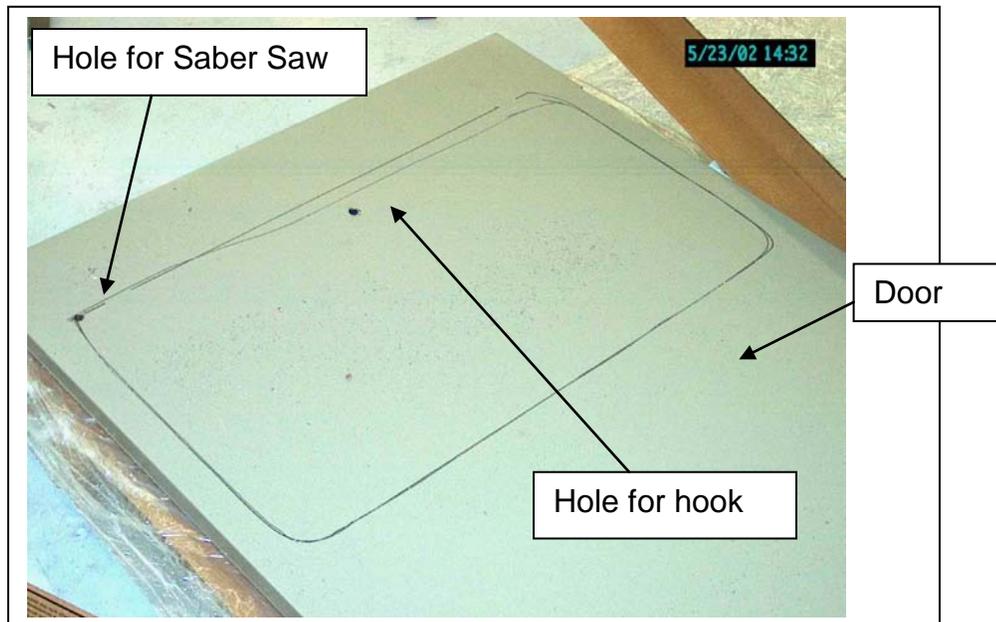
### **1.1. Customer**

The customer utilization and owner of this performance test is internal to Steelcraft Manufacturing, in the Research and Product Development Department. The customers identified for surveying include Lab Technicians, Operators, Process Engineers, Field Service, and Management. A survey has been constructed to identify the needs and concerns of the customer. The 9

customer surveys and the results along with a pros and con analysis were used to help design an alternative solution to enhance the process that is currently performed today (see Appendix B). The results of the survey are used in the QFD House of Quality, in the identification of customer expectations (see Appendix C).

## 1.2. **Research – Testing Fixture**

The current process is setup and performed by a Steelcraft lab technician. The doors weighing approximately 90 lbs. each are manually slid onto an electric hand operated fork lift, lowered to the ground and manually slid onto another skid that is on the floor (see figure 1). A template is set on the face of the door and traced with a permanent marker (see figure 2). Two holes are drilled, one in the



**Figure 2 Template traced, Cut, and drilled**  
center of the template nearest the end. This hole is used to insert the hook that is attached to the force gauge. The other hole is in one of the corners of the already

marked rectangle to insert the blade of a saber saw. The entire perimeter of the rectangle is cut through to the core material. A heavy steel frame is placed onto the door and aligned to each edge, with the hook centered over the hole (see figure 1). The handle is manually cranked by the lab technician to lower the hook to ensure proper engagement of the hook into the hole in the face of the door skin. The lab technician turns the handle while reading the gauge as the skin is peeled away from the core material, breaking the bond. The maximum force required to separate the steel face sheet from the core material is observed by the technician and recorded on paper and subsequently recorded in a lab report. The data collected from the test can be used for many purposes, including evaluation of less expensive adhesives to continually bring Steelcraft's material cost to a minimum, or to provide Steelcraft with more than one adhesive supplier. This test also provides information on whether the adhesive meets or exceeds the minimum force of 300 pounds [3] to separate the laminated composite.

The time, manual labor, data accuracy, and repeatability are addressed in the use of the new fixture. The main justification for the need of this new fixture is the cost savings, which will follow the successful implementation of this Adhesion Testing Fixture (see Appendix G). The current process cost Steelcraft \$7602 a year. The implementation of the semi-automatic Adhesion Testing Fixture will reduce Steelcraft's cost to \$1900 a year. This saving of \$5701 will allow payback in approximately 3.5 to 4 months.

Research has been completed on this testing process utilizing the USPTO (United States Patent and Trademark Office) website [4]. Ingersoll-Rand and

Steelcraft are not infringing on any patents or trademarks by implementing the enhancement of this testing process. There are no other testing processes publicly announced, giving Steelcraft Manufacturing a competitive advantage by having the test available whenever changes are required in the steel, core material, or adhesive.

## 2. Performance Objectives

Measurable performance objectives of the new semi-automatic fixture are force, time, weight of sample being tested, the accuracy of data collected and compliance with the industry standards. The force is measured to verify the adhesive bond strength between the core material and the door skins meets Steelcraft's standards. The time to setup the test will be reduced by 75% saving Steelcraft money. The sample size can be reduced from a 3-foot x 7-foot sample down to a 1 foot x 1 foot sample. Refer to the Proof of design concepts and benefits (see Appendix A). The new fixture will be in compliance with the Standard ASTM C297-94 (see Appendix I). The current process as it is performed is not compliant with the above mentioned industry standard because the standard specifies that the machine maintains a controlled loading rate with an accuracy of 1%. The ergonomics alone of the current process will not allow this type of accuracy.

The objective is to reduce the time required by a Steelcraft lab technician to setup and perform the test through capital equipment improvements in the Research and Product Development department at the Steelcraft Manufacturing facility in Cincinnati, Ohio. The capital equipment improvement consist of designing and building a semi-automatic pneumatic fixture that adapts to an Instron Machine (see figure 3). An Instron Machine utilizes electromechanical and servo-hydraulic technology to perform tensile, fatigue, structural, hardness and impact testing [5]. This fixture increases the throughput by allowing the lab

technician to perform more tests in the same amount of time currently allotted for testing.



**Figure 3 Instron Machine**

In addition, the manual labor and possibility of injury will be eliminated with the utilization of the Adhesion Testing Fixture.

## **2.1. Budget**

A budget has been developed to allocate the appropriate funding to manufacture and purchase parts to make this fixture a success (see Appendix E). Steelcraft Manufacturing has confirmed their support and 100% funding with a signed letter from the General Manager of Operations, Chris Mosby (see Appendix J).

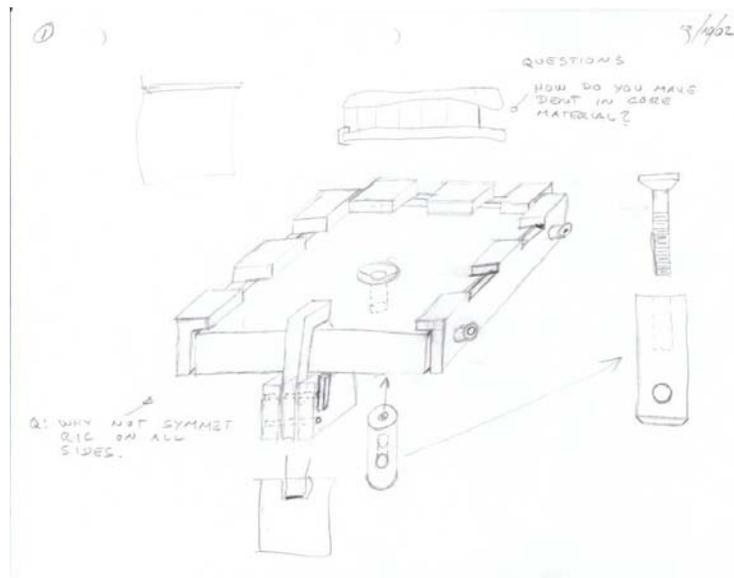
## **2.2. Schedule**

A schedule has been constructed to setup some disciplinary actions so the project stays on schedule to be presented at the Technical Exposition on May 16<sup>th</sup> and 17<sup>th</sup> of 2003 (see Appendix D).

### 3. Fixture Design Solutions

To accomplish the needs of the customer from the customer survey, 4 alternative design solutions were brainstormed and ideas sketched on pieces of paper. Each alternative solution was evaluated to see which would perform the best and would achieve the customers' needs.

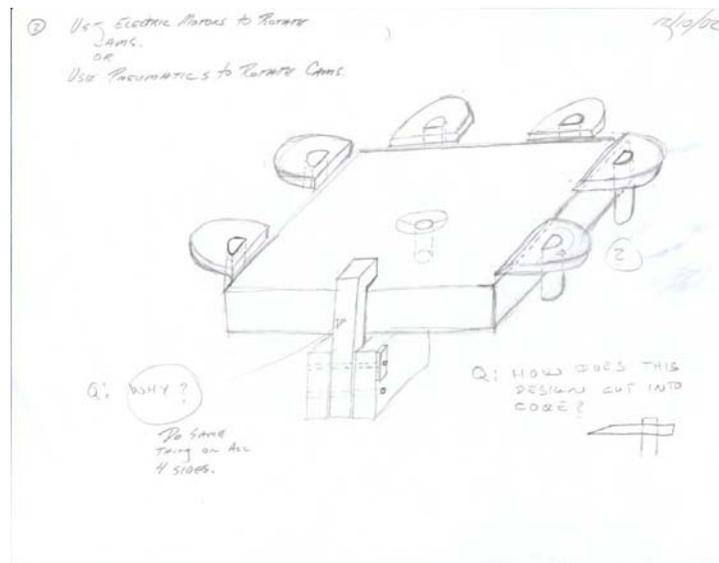
The Manual Thumb Turn design (see figure 4), has too much manual intervention involved by tightening each thumb turn bolt. Also this design doesn't



**Figure 4 Manual Thumb Turn Design**

allow the core material to be punctured. The lab technician has to use some persuasion such as a hammer to pound on each side in order to tighten the thumb turn bolts. The Manual Thumb Turn design will not meet the time reduction requirement in the proof of design (see Appendix A).

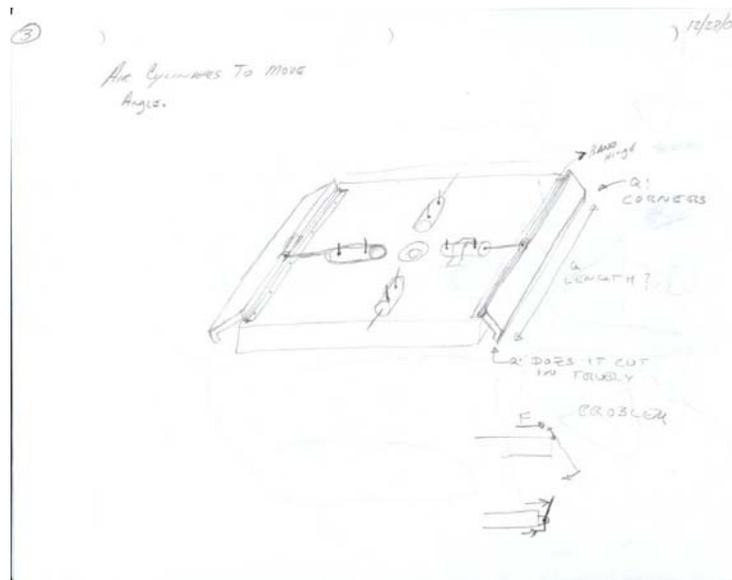
The Cam Driven design (see figure 5) takes out the manual intervention but may have a tendency to cause problems in maintaining the same amount of consistent pressure on the cams while rotating the cams at the same instance in time. The rod connection is not an off the shelf item and will have to be machined. The cams are not off the shelf items and will also have to be machined to a tighter tolerance than the rods, which will increase the cost due to accuracy.



**Figure 5 Cam Driven Design**

The Hinge Design (see figure 6) is relatively simple. With the use of pneumatic cylinders pivoting the clamping sides with the use of a piano hinge. The problem with this design is the pivoting point. An extreme amount of stress

will be dispersed to the hinge from the pneumatic cylinder because of the forces required to depress the core material (see Appendix G). The pneumatic cylinder would have a tendency to rise during actuation because of the connection to the hinge. The connection to the hinge is critical because this could require the cylinder to accept the opposing forces coming from the hinging system, which in turn could reduce the force exerted by the cylinder and the design will not function properly.



**Figure 6 Hinge Design**

The Linkage Design (see figure 7) uses a linkage to transmit the power to the clamping medium on the sides. The problem with this design is that the pneumatic cylinder would get hit by the rotating cam in the center of the device (see figure 8).

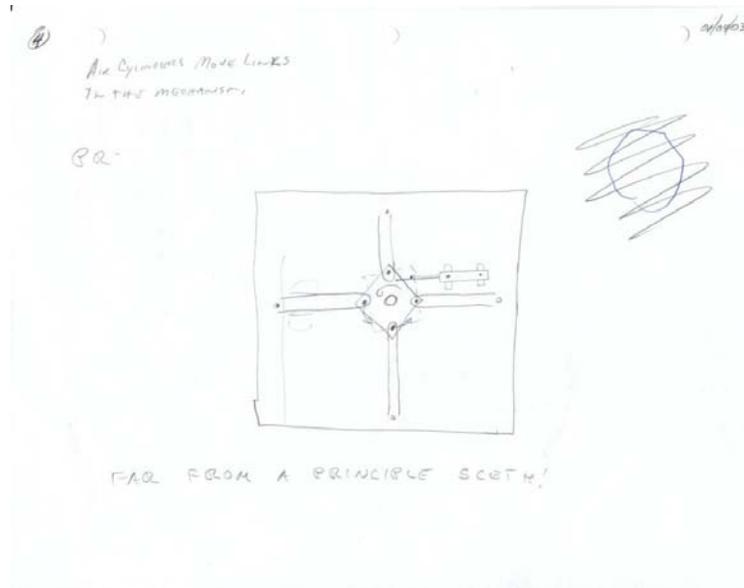


Figure 7 Linkage Design

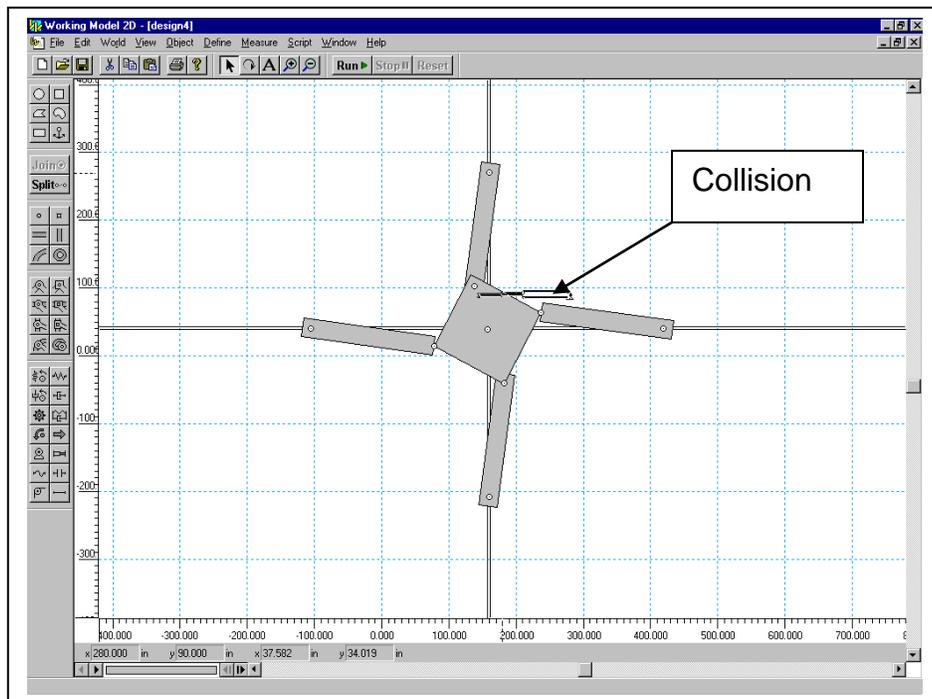


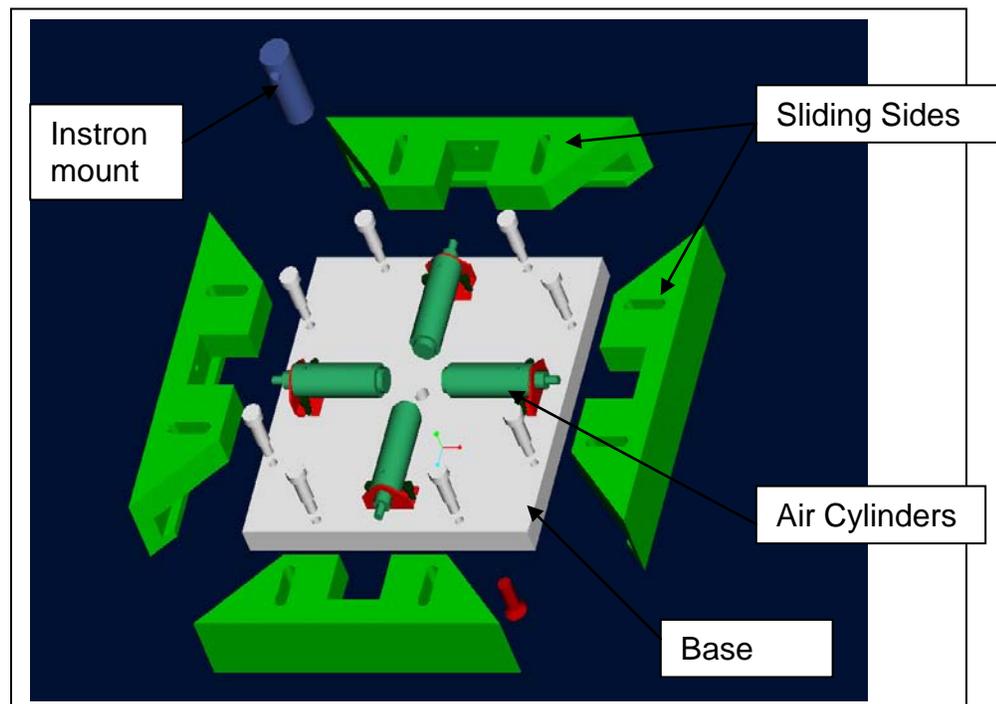
Figure 8 [6] Linkage Design Simulation

The solution part of the alternative selections was one of the most difficult and hard to grasp because the customer had to be satisfied and also has the final say in the functions of the design. The sole purpose is to meet their every need as long as safety and cost justification qualifies to their expectation because the customer is paying the final bill.

## 4. Design of Preference

The selection making process begins with the results of the customer survey [7] (see Appendix B). The design characteristics from the House of Quality (see Appendix C) are used in a Pugh Concept Matrix [8] (see Appendix B). These design criteria are used to compare each Alternative Design to the existing design. Each alternative design is given a plus (+), minus (–) or same (s) depending on how the alternative design compares to the existing design. The alternative design with the most plus (+) sign's is the design alternative that should be considered as the design of choice.

The selected design (see figure 9) is a combination of Hinge Design

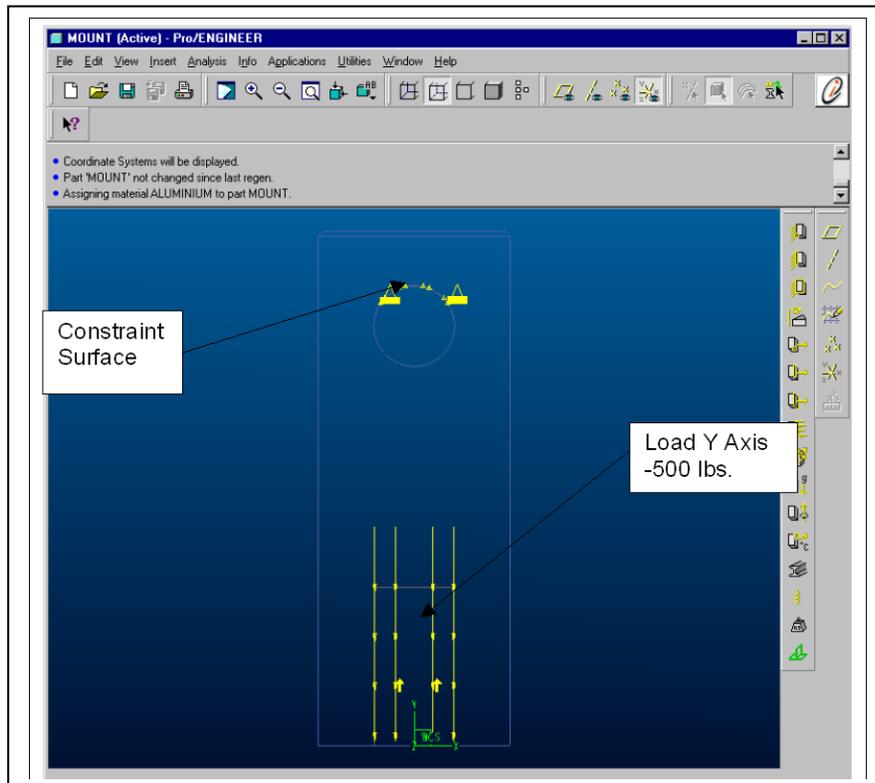


**Figure 9 Final Design**

and Linkage Design. The fixture consists of two of the apparatuses shown in figure 9. The other will be 180 degrees or mirror image from the one shown.

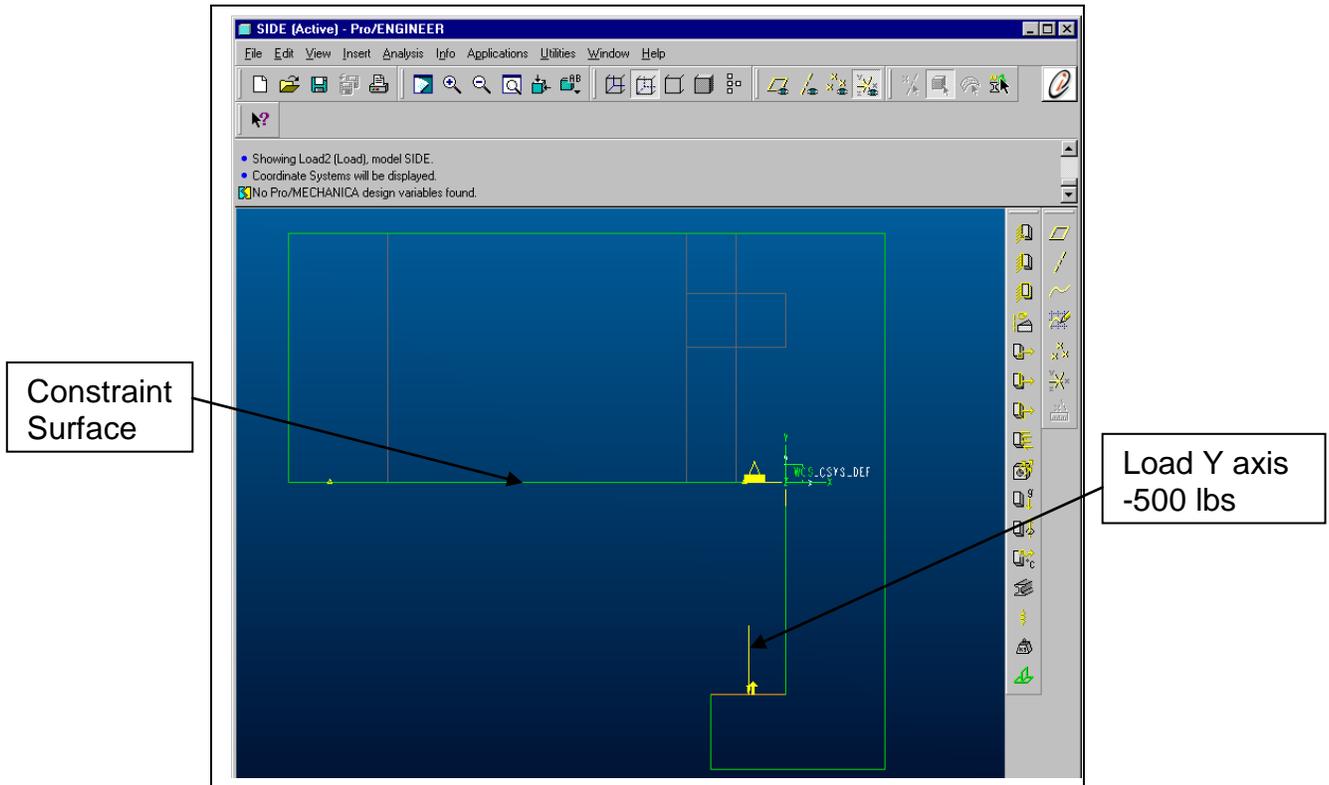
The pneumatic cylinders retract sliding the clamping sides to crush the core material to retain the material with a compressive force. The start button is pressed on the Instron computer and the sample is pulled apart registering the force required to separate the medium, which is recorded in a line graph format printed and stuck in the quality audit report generated by the lab technician.

The components of the fixture are modeled in 3 dimensional software called Pro/Engineer. Drawings (see Appendix F) created and simulated in Pro/Mechanica [9], which is a Finite Elements Analysis (FEA) software module of Pro/Engineer [10] (see Appendix G). The load applied to the models is derived from



**Figure 10 Mount FEA**

past legacy data as worse case scenario (see figure 10 and 11). The fixture consists of 4 sidepieces sliding back and forth. The load of –500 pounds was used on one side, which exceeds the load required because the force will be



**Figure 11 Side FEA**

distributed amongst all four sides. The maximum actual load on one side during operation will be 125 pounds, worst case.

The calculations for the pneumatic cylinder are critical because the cylinder needs to compress the core material (see Appendix G). The shear strength of the honeycomb core was used which is 14+/- 10% (see Appendix I).

The force required to crush the core material was calculated using  $P = \frac{F}{A}$ .

The pressure used in the formulas is standard shop air pressure at 90 psi. The same formula was used to calculate the area of the cylinder required that will exert the

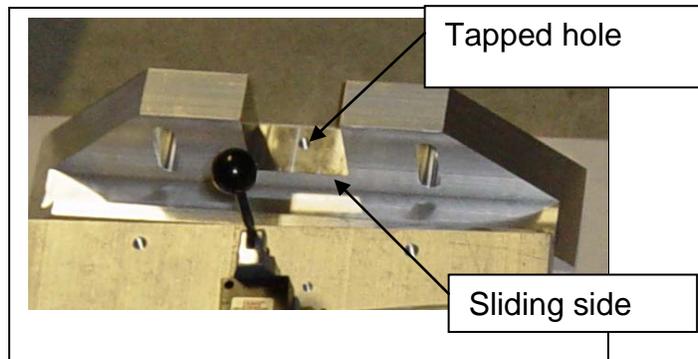
proper amount of force to crush the core material and grip the sheetmetal skins of the sample being tested. An area of  $0.714\text{in}^2$  was calculated for the cylinder bore. The area calculated is located on the ARO chart (see Appendix H). The 1-1/16" diameter bore cylinder was selected. The force exerted by this size cylinder is 80.1 lbs. With that amount of force, the acceleration can become excessive and is considered a possibility for injury. The acceleration is calculated with  $F = ma$ . The force is 80.1 lbs. and the weight of the side is 4.07 lbs. To convert the weight to mass in slugs, divide the weight by gravity,  $32.2\text{ft/sec}^2$  that yield  $0.126\frac{\text{lb}\cdot\text{ft}}{\text{sec}^2}(\text{slugs})$ . The acceleration is  $635.7\frac{\text{ft}}{\text{sec}^2}$ . The coefficient of friction of aluminum on aluminum is 1.35 [11]. The acceleration is reduced because of friction down to  $470.9\frac{\text{ft}}{\text{sec}^2}$ . Because of the high acceleration, a flow control valve is added to the schematic, which will take the acceleration potential out of the picture making the fixture safe to operate (see Appendix F) while still maintaining the proper amount of force to actuate the sides and crush the core material.

## 5. Build and Test

The concept of the design has to transfer from idea sketched on paper to manufacturing drawings. The components can then be produced by the selected machine shop with no questions on the design or function of the components.

Steelcraft has elected to outsource the components that needed to be machined. Steelcraft has the capabilities to perform the machining, but did not have the resources available to produce the required machined components for completion of the testing fixture to be on display and functioning at “Tech Expo 2003” on May 16 and 17 2003. Blue Chip Tool and Steelcraft met on March 18, 2003 to review the drawings and answer any questions. The components were ordered from McMaster-Carr and Grainger allowing assembly and testing to begin in early April 2003. This schedule allowed for contingency actions if they prove to be necessary.

The machined parts were machined and picked up on April 17, 2003 and an air cylinder was assembled to one of the sliding sides which uncovered a problem that the tapped hole on the sliding side where the cylinders screws into was not deep enough (see figure 12).



**Figure 12 Sliding Side**

The cylinder rod became immovable inside the sliding sides and the cylinder had to be destroyed upon removal from the sliding side. This was a

setback. Out of 8, 7 sliding side pieces were not tapped deep enough for the engagement of the cylinder rod. Two pneumatic cylinders had to be repurchased and the sliding sides had to return to the machine shop to be tapped all the way through. Luckily the cylinders were stock items but building the fixtures was put to a halt for 5 days while the sliding sides were tapped all the way through. The hole was changed from 0.500 deep to a through hole. By doing this it is easier for the machining of the tapped hole because this will eliminate the need for the machinist to use a clean out or bottom tap for the removal of the excess material.

The assembly of one pneumatic cylinder to the side and the base allowed for the initial testing process to

continue by making sure the pneumatic schematic was correct (see figure 13).

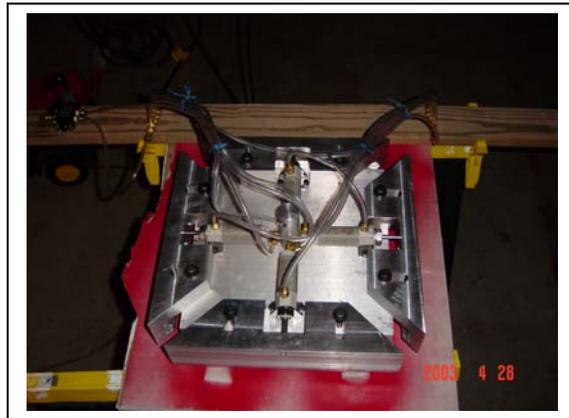
This testing corroborated that the flow control valve was positioned wrong.



**Figure 13 One Sliding Side Schematic Test**

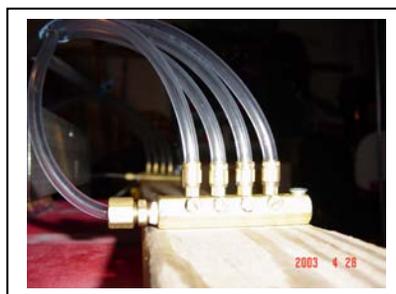
Further research was performed and discovered that the flow control valve needed to be on the exhausting side of the pneumatic valve to restrict the flow on the return but the initial amount of force during retraction or clamping is achieved. This is for safety reasons because the pneumatic cylinders have the capability of moving at exceptional speeds of approximately  $635.7 \frac{ft}{sec^2}$  (see appendix G).

The sliding sides were re-tapped and cylinders attached with no difficulties (see figure 14). Tubing was connected according to schematic, air compressor hooked up and the valve switched. The sliding sides simultaneously slid to the open position. Flipping the switch to retract the sliding sides uncovered a



**Figure 14 Top Half Assembly**

restriction of clamping force by the air cylinders not getting enough air. In figure 13, one air cylinder's clamping force is instantaneous. So that is what led to the manifolds as the restriction to the airflow (see figure 15). The manifolds reduced the opening where the air flows by 65% therefore starving the cylinders. The pneumatic tubing was reconnected without the manifolds and the instantaneous reaction was back with a clamping force of approximately 70 psi.



**Figure 15 Restricting Manifolds**

## 6. Fixture Testing

Testing was conducted on the fixture by mounting the fixture to the Instron machine and running 15 door samples through the pull test. In this test the fixture holds the door samples, and the Instron machine pulls the sample apart separating the two door skins while registering the force required to break the adhesive bond and showing the data in a chart. Professor Kettil Cedercrutz, the advisor for this testing fixture design project, has observed the operation and approved the fixture as a working prototype for the Technical Exposition on May 16 and 17 of 2003. The results from one of the pull tests are shown in figure 16 below. The chart shows the peak load required to separate the material.

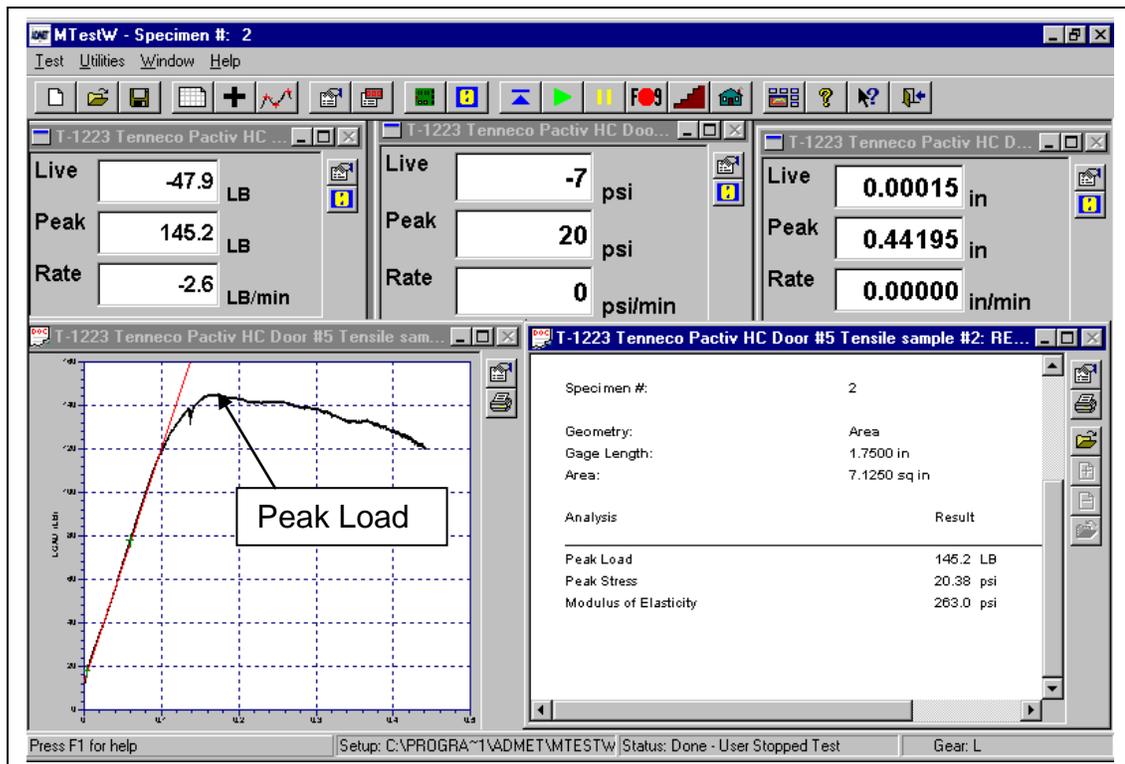


Figure 16 Test Results

## 7.

## Conclusion

The current process is performed on a regular basis and is labor intensive. The proposed process consists of semi-automating the pull test with an Instron - tensile/compression machine in the R & D lab at Steelcraft. A fixture is designed to adapt to the Instron machine that allows for the pull test to be performed and the data recorded to a computerized spreadsheet format. This data is more accurate because of the repeatability of the machine and because the data are recorded by a computer rather than read by an operator from a force gauge. The Adhesion Testing Fixture increases the throughput and eliminates the manual labor and possibility of human error in the manual setup, to save the company money and time, while reducing the possibility for injury.

The Adhesion Testing Fixture has accomplished 75% reduction in the setup time, which is a cost saving of \$5700 per year. A 90% weight reduction has been achieved in the sample being tested because the old test used 3' x 7' sample size and the new fixture uses a 12" x 12" sample. The process is repeatable and the data accuracy is better than  $\pm 1\%$ . And the fixture is now compliant with ASTM C297-94.

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Specifications for swinging doors that covers size, design, materials,  
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simulating everyday abuses and uses operating conditions.
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Specific specifications on the construction of a hollow metal door.

HMMA 850-83 pg. 1-2, "Fire-Rated Hollow Metal Doors and Frames", Second Edition  
Hollow Metal Manufacturers Association  
©1983 National Association of Architectural Metal Manufacturers  
Specific specifications on the construction of a hollow metal door that contains a specific Fire Label for a specific purpose or use.

K. Roeper, Product Manager, Steelcraft Manufacturing,  
Interview, October 2002.

Mr. Roeper was the Research and Product Development Department Manager for 10 years and is experienced with the tests described above prior to being challenged with a position as Product Manager. Mr. Roeper has worked at Steelcraft Manufacturing for 17 years.

K. Bishop, Lab Technician, Steelcraft Manufacturing – Research & Product Development Department,  
Interview, October 2002.

Mrs. Bishop is the Lab Technician who solely owns the process of performing the peel test. Mrs. Bishop has been employed by Steelcraft for 16.5 years and has been performing the peel test for 15 of those 16.5 years. Mrs. Bishop is considered to be the expert in this process.

S. Wamsley, Supplier Quality Engineer, Steelcraft Manufacturing – Purchasing Department,

Mr. Wamsley is the Quality Engineer who is responsible for making sure the core material meets or succeeds the requirements of a Steelcraft Door.

Tim Dunn, Buyer, Steelcraft Manufacturing – Purchasing Department,

Mr. Dunn buys the core materials that meet or succeed the requirements of the Steelcraft Door.

Fred Barth, Tooling Engineer – Steelcraft Manufacturing,

Mr. Barth designs the punch and dies that are used on the production lines in manufacturing.

Brian Wottle, Process Engineer – Steelcraft Manufacturing,

Mr. Wottle is a Process Engineer in manufacturing who maintains the fabrication lines with enhancements in the technology as it changes.

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