REUSABLE MATERIAL FOR DROP TOWER

A thesis written at

TANK AUTOMOTIVE RESEARCH AND

DEVELOPMENT ENGINEERING CENTER (TARDEC)

and submitted to

KETTERING UNIVERSITY

in partial fulfillment
of the requirements for the
degree of

BACHELOR OF SCIENCE IN MECHANICAL ENGINEERING

by

HOLLY CLENDENING

August 2011

Ms. Holly Clendening
Author

Mr. Christopher Felczak
Employer Advisor

Dr. Janet Brelin-Fornari
Faculty Advisor

Report Documentation Page	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
29 AUG 2011	**Masters Thesis**	**06-04-2010 to 11-07-2011**

4. TITLE AND SUBTITLE **REUSABLE MATERIAL FOR DROP TOWER**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) **Holly Clendening**	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U.S. Army TARDEC,6501 East Eleven Mile Rd,Warren,Mi,48397-5000**	8. PERFORMING ORGANIZATION REPORT NUMBER **#22249**
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) **U.S. Army TARDEC, 6501 East Eleven Mile Rd, Warren, Mi, 48397-5000**	10. SPONSOR/MONITOR’S ACRONYM(S) **TARDEC**
	11. SPONSOR/MONITOR’S REPORT NUMBER(S) **#22249**

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
This thesis represents the capstone of my five years combined academic work at Kettering University and job experience at Tank Automotive Research and Development Engineering Center (TARDEC). Academic experiences in Mechanical Engineering proved to be valuable assets while I developed this thesis and addressed the problem it concerns.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Public Release**	**57**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

DISCLAIMER

This thesis is submitted as partial and final fulfillment of the cooperative work experience requirements of Kettering University needed to obtain a Bachelor of Science in Mechanical Engineering Degree.

The conclusions and opinions expressed in this thesis are those of the writer and do not necessarily represent the position of Kettering University or Tank Automotive Research and Development Engineering Center (TARDEC), or any of its directors, officers, agents, or employees with respect to the matters discussed.

Reference herein to any specific commercial company, product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or the Department of the Army (DoA). The opinions of the authors expressed herein do not necessarily state or reflect those of the United States Government or the DoA, and shall not be used for advertising or product endorsement purposes.

PREFACE

This thesis represents the capstone of my five years combined academic work at Kettering University and job experience at Tank Automotive Research and Development Engineering Center (TARDEC). Academic experiences in Mechanical Engineering proved to be valuable assets while I developed this thesis and addressed the problem it concerns.

Although this thesis represents the compilation of my own efforts, I would like to acknowledge and extend my sincere gratitude to the following persons for their valuable time and assistance, without these individuals this thesis would never have been possible:

1. Mr. Chris Felczak for the jokes, entertainment, and in all seriousness the guidance.
2. Dr. Janet Brelin-Fornari for being a great mentor and teacher.
3. Mrs. Risa Scherer for the guidance and all of the contacts supplied in order to finish this thesis.
4. Mr. Kyle McLeod for the wisdom and the suggestion of this project.
5. My team members for constantly asking if my thesis was finished.
6. My husband, family, and friends for ALL of the heartfelt support in every other aspect of my life so that this thesis could finally become reality.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Figures **Page**

Appendices

Tables

Appendices

I. INTRODUCTION

The Tank Automotive Research, Development and Engineering Center (TARDEC) develops, integrates and sustains technology solutions for all manned and unmanned Department of Defense (DoD) Ground Systems and Combat Support Systems to improve Force effectiveness and provide superior capabilities for the Future. The Ground Systems Survivability (GSS) Blast Mitigation Team (BMT) requires capabilities to evaluate, optimize, and integrate occupant protection systems into current and future Army ground vehicles that mitigate injury due to blast and crash events. The use of the drop tower helps in these endeavors and is an integral part of replicating and evaluating those events.

Problem Topic

Currently, commercially available reusable energy absorbing material is not available for use with the drop tower at TARDEC.

Background

Currently TARDEC utilizes a drop tower that uses aluminum honeycomb, see Figure 1 to decelerate the carriage and transfer the desired impulse to the article being tested. The aluminum is intended for single use, and must be replaced after every test. The drop tower can run many times in a given day making it a necessity to keep large amounts of various aluminum honeycombs on hand. Additionally, the honeycomb is sold in large sheets, making it necessary to cut and prep individual pieces for use in testing. Each honeycomb design exhibits different performance characteristics and requires additional test runs to validate the impulse prior to testing with an instrumented dummy.

Figure 1. Aluminum Honeycomb.

Finding an alternative, re-usable and cost effective material for decelerating the drop tower will enable testing to be completed rapidly and at a lower cost to the test requestor of the test arrangement. It will also reduce material waste produced from each event.

Criteria and Restrictions

Possible material solutions will be evaluated to determine their properties and how they perform during drop tower testing. Ideal material(s) would:

1. Perform equivalent to that of aluminum honeycomb (i.e. transfer the same impulse to the drop carriage) or within +/-2% standard deviation of current material
2. Be re-usable/resettable for a minimum of X runs

3. Be less cost intensive than aluminum honeycomb (taking the total sum of honeycomb, including storage, handling, time to cut, etc, used over life the of the reusable material, including storage, handling, time to cut, etc.)

Methodology

The process by which the thesis will be performed is given by the following steps:

1. Information will be gathered from the drop tower.
2. Materials characteristics will be researched.
3. Materials will be chosen for testing in the drop tower.
4. Materials will be evaluated to determine performance.
5. Material impulse responses will be analyzed.
6. Recommendations on the best suited materials for the drop tower.

Primary Purpose

This thesis presents the results of the investigation into reusable energy absorbing materials.

Overview

The following content contains conclusions, recommendations, documentation, and supporting information pertaining to the investigation into reusable energy absorbing materials.

II. MATERIAL TESTING

The drop tower located at the Selfridge Air Force and National Guard (SANG) Base is used to evaluate the Anthropomorphic Test Device (ATD) response to occupant protection technologies, such as seats, energy absorbing materials, and restraints. The data received from these drop events provide relevant information regarding what a human may experience under similar events. Generally, engineers can evaluate seat related items by correlating blast data received from Live Fire Test & Evaluation data to the response of the ATD in a drop tower event. It is pertinent that the drop tower be well maintained and readily available. Drop tower setup and usage is critical to successfully design and evaluate occupant protection systems for military ground vehicles.

Current Drop Tower Material & Setup

The material that is currently used to decelerate the drop tower is aluminum honeycomb. The density and cell size of the honeycomb, see Figure 2, determines the energy absorption of the honeycomb. The test performer can determine from the various crush strengths which cell size, and associated characteristics, to use for optimal results.

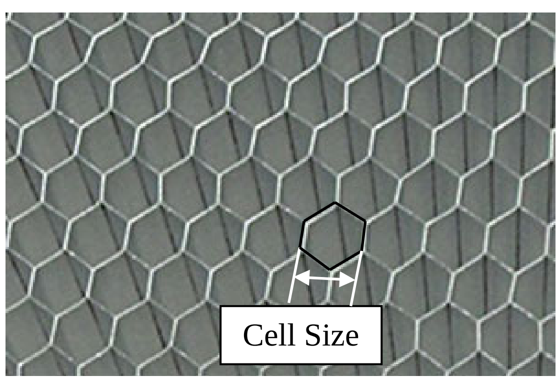


Figure 2. Aluminum Honeycomb Cell Size.

The aluminum honeycomb currently used in the drop tower is material number A8 and A9 in 2’x 3’ sections, their material properties can be found in Appendix A, Table 1. Figure 3 and Figure 4 illustrate the impulse for material A8 and A9 currently used in the drop tower test. Both samples were tested with the carriage and dropped from a set height and no additional weight.

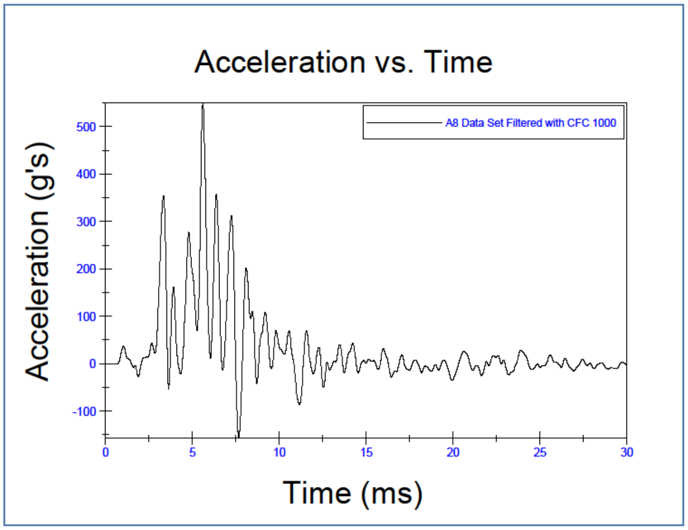


Figure 3. Material A8 Impulse Graph.

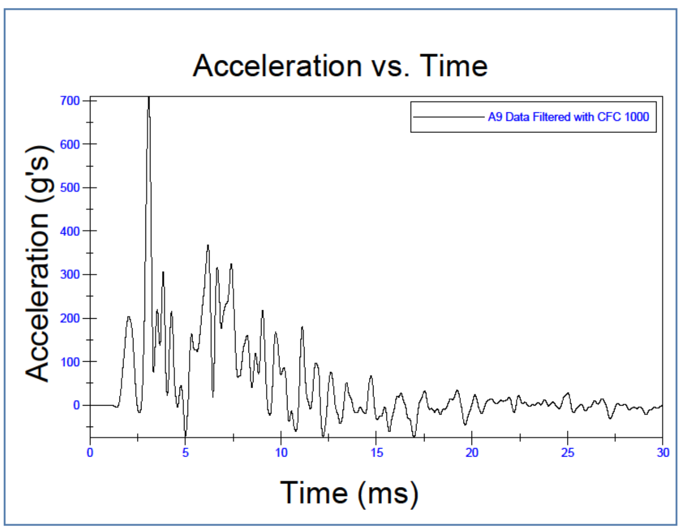


Figure 4. Material A9 Impulse Graph.

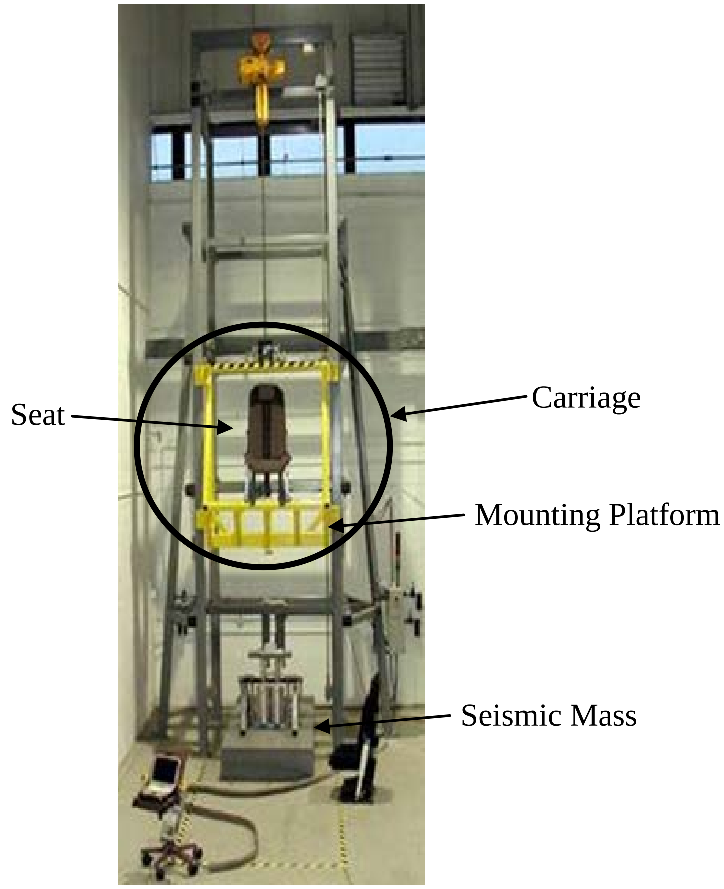


Figure 5. Drop Tower Test Setup.

The setup for the drop tower is shown in Figure 5. As stated previously the 2’x 3’ sections of aluminum honeycomb are placed beneath the carriage as a decelerative medium. Beneath the aluminum honeycomb is a seismic mass that prevents the large mass of the carriage, seat and ATD from altering the drop tower setup. The carriage holds one seat and ATD for each test event. The tower is controlled externally by a laptop and the data is controlled and recorded onto an external desktop computer. The information regarding characteristics of the drop tower and the carriage are shown below in Table 1.

Table 1

Drop Tower and Carriage Characteristics

DROP TOWER	Measurement	Units
Height	~27	ft
Width	~8	ft
Depth	~13	ft
CARRIAGE		
Height	~6	ft
Width	~4	ft
Depth	~3	ft
Weight	475-480	lb_f

Bowling Ball Rubber Material Sample Test & Setup

An array of 1' x 1' rubber material samples were purchased for evaluation in this study. These samples were chosen to cover numerous types of thicknesses, durometer ratings, and chemical compositions. The list of these materials is available for reference in Appendix A, Table 2.

The bowling ball rubber material sample test is used as a rudimentary tool to judge the dampening characteristics and properties of a material. The less the bowling ball rebounds from its initial drop height the less vibrations will be transferred into the bowling ball from the drop. This test is beneficial for many reasons. First, the test is conducted on a smaller drop weight than with the carriage actual weight. The smaller drop weight is easier to setup than the drop tower therefore not wasting time and resources. Second, materials that cannot withstand this smaller drop weight are easily eliminated from the options of potential honeycomb replacements. Third, identifying materials that lessen the vibrations of the bowling ball translates into less vibration in the carriage thus creating less risk of large scale damage and transferring the vibration to the test specimen. Figure 6 illustrates the test setup.

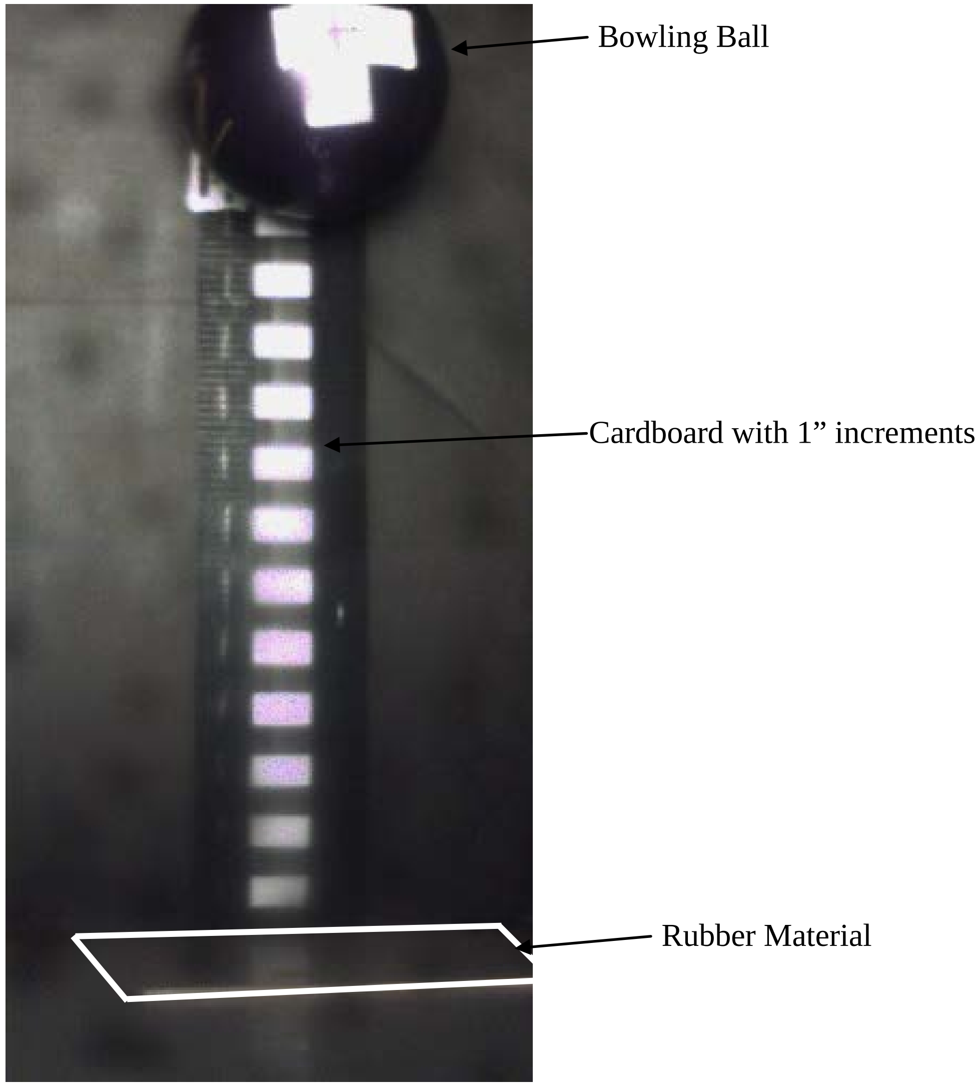


Figure 6. Ball Drop Test Setup.

A 13lb bowling ball was dropped from heights varying around 24 ± 5 inches. Cardboard with one inch increments was placed behind the test setup as a point of reference for later analysis. A cross mark was made on the side of the bowling ball in order to follow the bowling ball in the video and the ball was dropped with as little rotation as possible. Due to the human variability in this test the drop heights varied. The tests were recorded, viewed and analyzed using Phantom high speed camera by Vision Research, see

Appendix E for more information regarding this system. The results were analyzed and calculated and listed in Table 2.

Table 2

Ball Drop Test Results

Material Number	Run	Material	Initial Drop Height (in)	Initial Rebound	Number of Rebounds	Percentage of Initial Height Rebound (%)
R2	1	Butyl Rubber				
R2	2	Butyl Rubber				
R3	1	Buna Rubber	30.583	2.750	4	9%
R5	1	EPDM Rubber	20.532	4.363	6	21%
R5	2	EPDM Rubber	22.584	4.010	6	18%
R6*	1	Gel Rubber	23.125	6.500	5	28%
R7	1	Gum Rubber	20.353	8.706	7	43%
R7	2	Gum Rubber	21.957	8.109	6	37%
R8	1	Hypalon Rubber	23.481	1.796	3	8%
R8	2	Hypalon Rubber	20.670	1.409	3	7%
R9	1	Natural Rubber (Neoprene)	19.101	4.651	4	24%
R9	2	Natural Rubber (Neoprene)	21.188	5.563	4	26%
R10	1	Nitrile Rubber	23.933	3.533	3	15%
R10	2	Nitrile Rubber	20.765	3.235	3	16%
R11	1	PVC Rubber	21.770	2.682	3	12%
R11	2	PVC Rubber	21.434	2.231	3	10%
R12	1	Santoprene Rubber	21.396	2.308	5	11%
R12	2	Santoprene Rubber	23.533	2.733	4	12%
R13	1	SBR Rubber	27.000	3.800	4	14%
R13	2	SBR Rubber	22.188	3.625	4	16%
R14	1	Vinyl Rubber	21.081	1.351	2	6%
R12	2	Vinyl Rubber	22.688	1.561	3	7%
R15	1	Viton® Fluoroelastomer Rubber	23.880	1.488	2	6%
R15	2	Viton® Fluoroelastomer Rubber	25.375	2.379	3	9%

*Bowling Ball Penetrated the Rubber Material, see Appendix A for visuals.

Due to material unavailability and limited test resources, Material R2 was not tested in the Ball Drop Testing.

In order for the material to pass the bowling ball test the material needed to be visually undamaged, for example no punctures or permanent deformations. Material R6 was punctured during the Ball Drop Test and became permanently deformed therefore it was eliminated as a material solution for the drop tower. Although Material R15 yielded low percentage of rebound and was visually undamaged the size of the material available for purchase is too small to run in the drop tower test.

Drop Tower Rubber Material Sample Test & Setup

The drop tower rubber material was setup as shown in Figure 7.

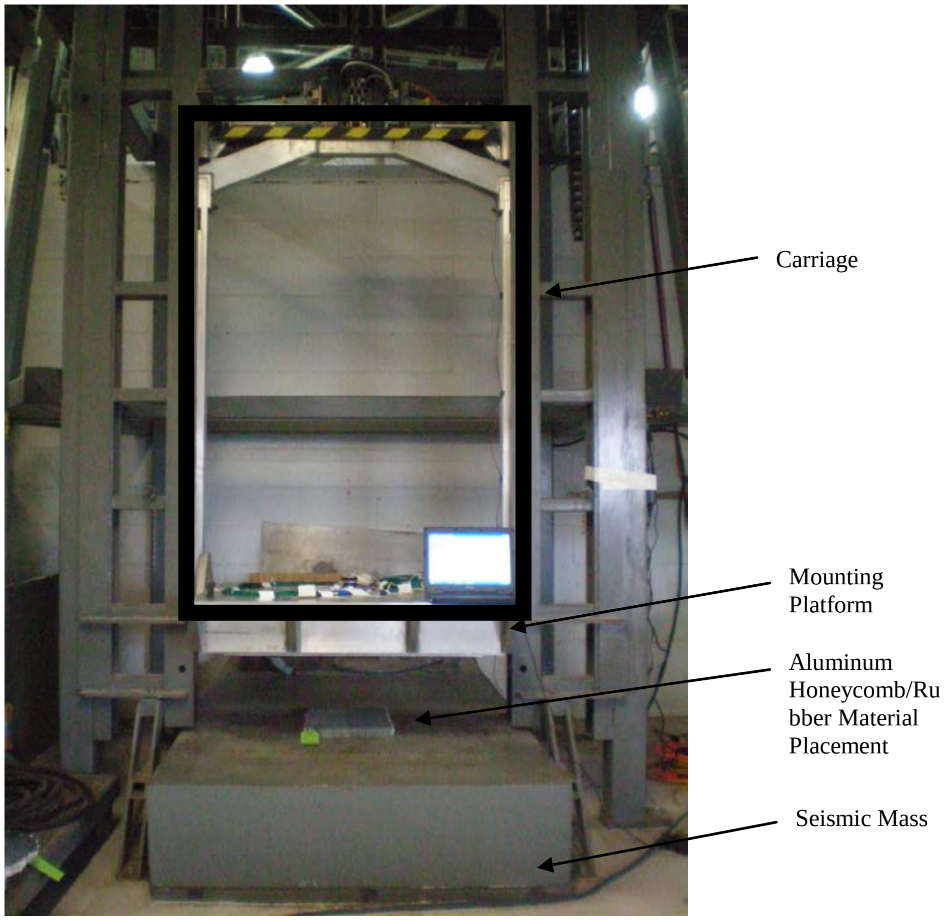


Figure 7. Drop Tower Material Sample Test Setup.

In this setup the rubber material was placed directly beneath the carriage. The centers of the materials were aligned to the center of the carriage. The carriage was then raised to 1 ft above the top of the material and then dropped. Material tests were run sequentially. Each material was tested three times for comparison, unless noted otherwise. In addition to the rubber materials being tested, the aluminum honeycomb was tested for comparison purposes.

The following table shows the resulting impulse for each material as filtered with a CFC 1000 filter. The acceleration plots for these tests are located in Appendix C. Information regarding the filter selected is located in Appendix E.

Table 3

Material Impulses Filtered (CFC 1000)

RUBBER MATERIAL

Material	Run	1'	Material	Run	1'
	1	Peak g's - 364.25		1	Peak g's - 282.41
R2	2	Peak g's -	R12	2	Peak g's -
	3	Peak g's -		3	Peak g's -
	1	Peak g's - 397.72		1	Peak g's - 184.31
R3	2	Peak g's - 389.76	R13	2	Peak g's - 173.11
	3	Peak g's -		3	Peak g's - 130.50
	1	Peak g's - 380.54		1	Peak g's - 476.93
R5	2	Peak g's - 383.32	R14	2	Peak g's - 497.03
	3	Peak g's - 393.39		3	Peak g's -
	1	Peak g's -		1	Peak g's -
R6	2	Peak g's -	R15	2	Peak g's -
	3	Peak g's -		3	Peak g's -
	1	Peak g's -			
R7	2	Peak g's -			
	3	Peak g's -			
	1	Peak g's - 372.71			
R8	2	Peak g's - 269.79			
	3	Peak g's -			
	1	Peak g's - 62.00			
R9	2	Peak g's - 70.12			
	3	Peak g's - 70.01			
	1	Peak g's - 84.27			
R10	2	Peak g's - 109.18			
	3	Peak g's - 129.62			
	1	Peak g's - 460.51			
R11	2	Peak g's - 614.64			
	3	Peak g's - 605.71			

ALUMINUM HONEYCOMB

Material	Run	1'
	1	Peak g's -
A1	2	Peak g's -
	3	Peak g's -
	1	Peak g's -
A2	2	Peak g's -
	3	Peak g's -
	1	Peak g's - 31.16
A3	2	Peak g's - 32.01
	3	Peak g's - 31.82
	1	Peak g's - 34.22
A4	2	Peak g's - 38.50
	3	Peak g's - 33.81
	1	Peak g's - 57.39
A5	2	Peak g's - 54.68
	3	Peak g's - 49.52
	1	Peak g's - 49.03
A6	2	Peak g's - 53.82
	3	Peak g's - 52.58
	1	Peak g's - 41.43
A7	2	Peak g's - 38.84
	3	Peak g's - 38.31
	1	Peak g's - 55.82
A8	2	Peak g's - 62.98
	3	Peak g's - 50.51
	1	Peak g's - 138.08
A9	2	Peak g's - 122.58
	3	Peak g's - 122.59

*Peak g's are estimated
Shaded cells are materials that were not tested due to extreme reaction, material size, or permanent deformation during Ball Drop Test.

Material A1 was tested but after one test the material sheered in half. Although the sheering was unexpected the material was expected to perform poorly because of the very low psi rating on the material. Due to this information and result Material A1 run 1 data was inaccurate and not included; runs 2 & 3 were not performed. Again Material R6 was not tested in the drop tower sample test because Material R6 was punctured during the Ball Drop Test and became permanently deformed. Material R7 experienced a bouncing reaction causing the carriage, after impact, to rise and impact the rubber mat again 4-5 times. It was also eliminated as a suitable alternative material for the above mentioned reasons. Materials R2, R3, R8, R12 and R14 were tested less than three times due to the violent reaction of the impact, the structure resonated with a sound that resembled a solid structure colliding with another solid structure, for example the carriage hitting the seismic mass. Material R12 moved completely from under the carriage and therefore run 1 data was inaccurate and not included; runs 2 & 3 were not performed. Previously tested ¼” thick samples of rubber were subjected to violent impacts, compressing the materials and endangering the carriage, or moved out from under the carriage. Further testing was not performed on these materials and the materials were eliminated as an alternative material due to the danger the material could potentially pose. Due to this test observation Material R15 was not tested because the sample material was a ¼” thick 6” x 6” piece which was even smaller than all other test samples. It was also noted that many of the rubber materials stuck to the bottom of the carriage after each run, regardless of the thickness. Pictures of each material post impact are located in Appendix D.

III. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The materials that performed the best, according to smallest percentage of initial rebound height in the bowling ball drop test were R14 and R15. Testing was performed on all materials that passed the bowling ball drop test. Again Material R6 did not pass the bowling ball test.

The rubber materials tested showed no sign of visible deformation. The rubber material that best matched the desired impulse curve of the sample aluminum honeycomb material A8 was material R10 and A9 was material R13. This was determined by the similar peaks and valleys within the data shown in Figure 8 and Figure 9. In general, at a height of 1 foot, the time over which aluminum honeycomb creates an impulse is three times longer than that of rubber mats.

The following figures compare each aluminum honeycomb currently in use with the drop tower to all rubber mats tested in a ten millisecond window. Material R8 and R9 were divided into two graphs per material for ease of viewing when comparing with other data.

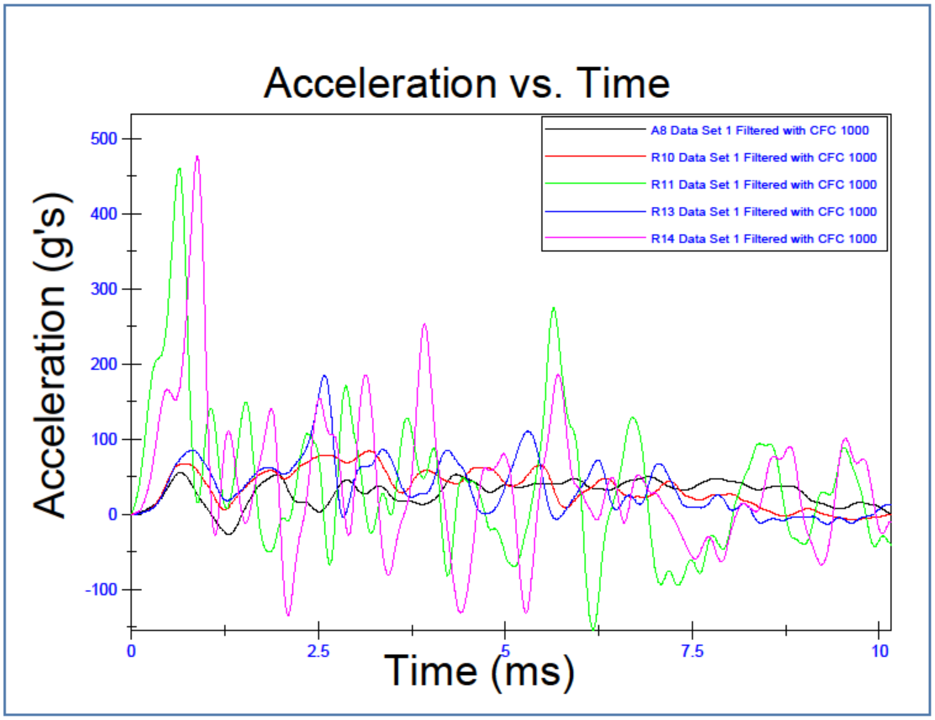
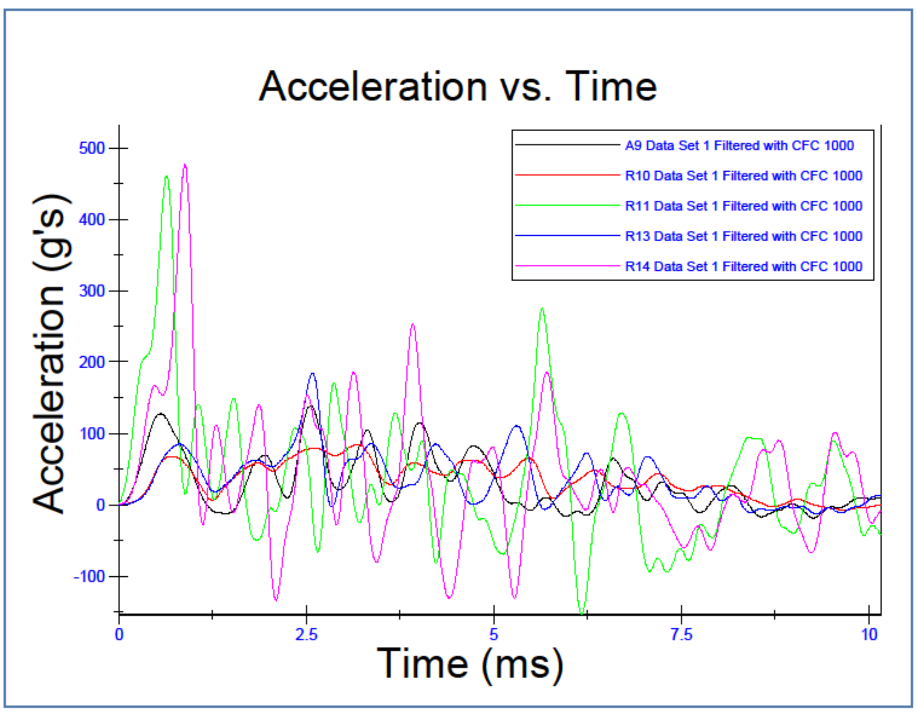
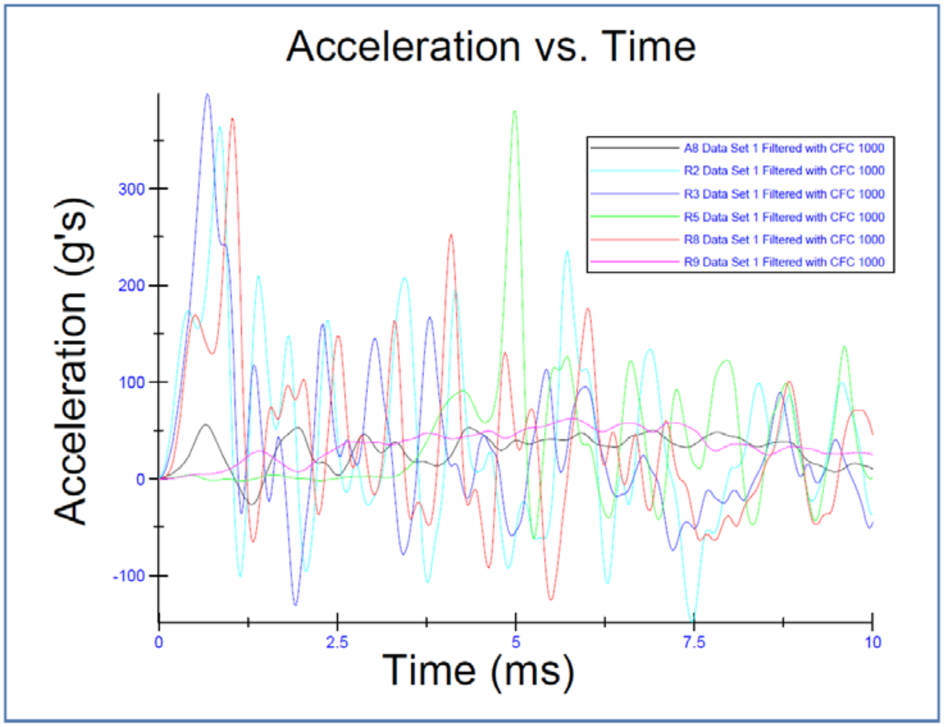


Figure 8. A8, R10, R11, R13, and R14 10 ms Graph.



<u>Figure 9.</u> A9, R10, R11, R13, and R14 10 ms Graph.



<u>Figure 10.</u> A8, R2, R3, R5, R8 and R9 10 ms Graph.

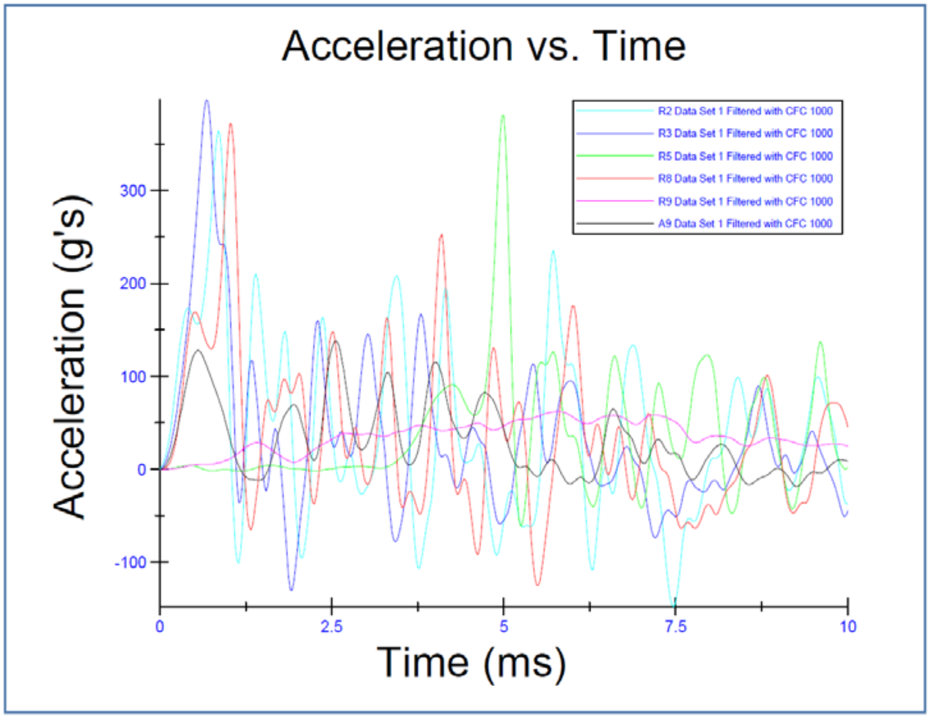


Figure 11. A9, R2, R3, R5, R8 and R9 10 ms Graph.

Recommendations

Recommendations in regards to the path forward are for testing rubber mats. Materials R10 and R13 were the closest performing materials to A8 and A9. The actual peaks and valleys are similar leading to believe there may be some value in further testing these materials in larger sizes, 3’x 1’, to accommodate higher drops. Calculations regarding maximum compressibility and the force needed to create that maximum compression will need to be done before performing higher drops to help determine if the material is being over compressed, creating materials responses similar to the ¼” materials tested.

The majority of the information presented in this thesis is utilizing 1’x 1’ test pieces. In an unrelated, side running test of larger aluminum honeycomb impact area, 3’x1’, at the same height it was noted that there is a difference in peak accelerations. Further testing in impact area of either aluminum honeycomb or rubber mats or both could supply alternate ways of testing that increase peak accelerations.

Extensive repeat testing is also recommended to help determine the life of each material in consideration as a drop tower material solution. The materials need to be tested until the peak response of the material changes more than a predetermined amount. In conversation it was mentioned that a 30 minute wait time between runs would be a sufficient time to start with and then potentially decrease depending on material response. Currently Material A9 is $52.83 per square foot and Material A8 is $20.00 per square foot. No rubber material was more than $160.00 per square foot so if any individual rubber material can be used as an alternative test piece for eight or more drop tests it is a less cost intensive solution as a material. Other factors such as storage, handling, time to cut, etc… should also be considered in the final life cycle cost estimate. In conjunction with this the waste produced by using rubber instead of aluminum should be investigated to identify whether or not rubber produces more or less waste and the repercussions of rubber disposal.

Finally all materials were tested as single sheets or mats. By layering materials, rubber on rubber, aluminum on aluminum, or even rubber on aluminum, the impulse will change. Research into the effects of the layering of materials may also supply alternate ways of testing that affect the impulse.

Other recommendations are in regards to the drop tower capabilities. First, the tools available to cut the aluminum honeycomb were difficult to use and required extensive prep time, including apparatus setup, aluminum honeycomb preparations, computer and program setup, and instrumentation setup, before tests. Having a more specialized tool, such as a large band saw, a specialty tool, would cut down on aluminum honeycomb preparations reducing the overall prep time allowing more tests to be run.

Secondly, there is no storage for the large sheets of aluminum honeycomb within the lab and therefore a second storage area must be utilized. Creating a storage system within the lab would also save overall prep time.

Finally, the limited resources that support drop tower usage, such as computers, software licenses, and sensors/data acquisition systems, create down time when more than one person has need of them or resources are eliminated. For example, if person A needs to use the only laptop that downloads data from the data acquisition system then person B cannot simultaneously test because the software needed to record the data is only on that one laptop. By purchasing extra equipment, such as laptops and computer software licenses, testing can become more efficient and employee’s can better use their time.

REFERENCES

Carriage. (2010). Retrieved December 06, 2010 from Farlex, Inc., The Free Dictionary: http://www.thefreedictionary.com/carriage.

Energy-absorbing. (2010). Retrieved December 06, 2010 from Farlex, Inc., The Free Dictionary: http://www.thefreedictionary.com/energy-absorbing.

GLOSSARY

Drop Tower	A fixture that allows a carriage to be vertically dropped creating an impulse.
Carriage	A moving part of a machine for holding or shifting another part.
Energy Absorbing	The capability of absorbing energy; as energy-absorbing bumpers reduce injury and damage in vehicle collisions.

APPENDICES

APPENDIX A

MATERIAL INFORMATION

Table A-1

Aluminum Test Material Properties

Material Number	Corrosion Coating?	Density (lbs/ft^3)	Cell Size	Thickness	Foil Alloy	Crush Strength
A1	Yes	1	3/8"	1"	5052	35 psi
A2	Yes	1.6	1/4"	1"	5052	50 psi
A3	Yes	2.3	1/4"	1"	5052	90 psi
A4	Yes	3	3/8"	1"	5052	120 psi
A5	Yes	3.4	1/4"	1"	5052	140 psi
A6	Yes	3.7	3/8"	1"	5052	180 psi
A7	Yes	4.3	1/4"	1"	5052	200 psi
A8	Yes	4.3	1/4"	3"	5052	200 psi
A9	Yes	8.1	1/8"	3"	5052	750 psi

Table A-2

Rubber Test Material Properties

Material Number	Material	Tensile Strength (psi)	Thickness (±Tolerance)	Width (±Tolerance)	Stretch Limit	Durometer Rating	Density
R2	Butyl Rubber	1500	1/4" ± 0.031"	12" ± 3/32"	300%	60A	84 lbs./ft^3
R3	Buna Rubber	1500	1/4" ± 0.031"	12" ± 1/4"	N/A	60A	N/A
R5	EPDM Rubber	1000	1/2" ± 0.047"	12" ± 1/8"	N/A	60A	N/A
R6	Gel Rubber	N/A	1/2" ± N/A	12" ± N/A	1200%	N/A	45-49 lbs./ft^3
R7	Gum Rubber	3800	1" ± 0.125"	12" ± 1/16"	N/A	60A	N/A
R8	Hypalon Rubber	1500	1/4" ± 0.031"	12" ± 3/32"	N/A	65A	N/A
R9	Natural Rubber (Neoprene)	1700	2" ± 0.25"	12" ± 3/8"	N/A	70A	N/A
R10	Nitrile Rubber	900	1" ± 0.100"	12" ± 1/2"	N/A	60A	N/A
R11	PVC Rubber	700	1/4" ± 0.031"	12" ± 1/2"	N/A	80A	N/A
R12	Santoprene Rubber	640	1/4" ± 0.031"	12" ± 3/32"	N/A	55A	N/A
R13	SBR Rubber	700	1" ± 0.1"	12" ± 1/2"	N/A	75A	N/A
R14	Vinyl Rubber	2000	1/4" ± 0.031"	12" ± 1/4"	N/A	70A	N/A
R15	Viton® Fluoroelastomer Rubber	1500	1/4" ± 0.031"	6" ± 1/4"	N/A	75A	N/A

APPENDIX B

RUBBER MATERIAL PICTURES

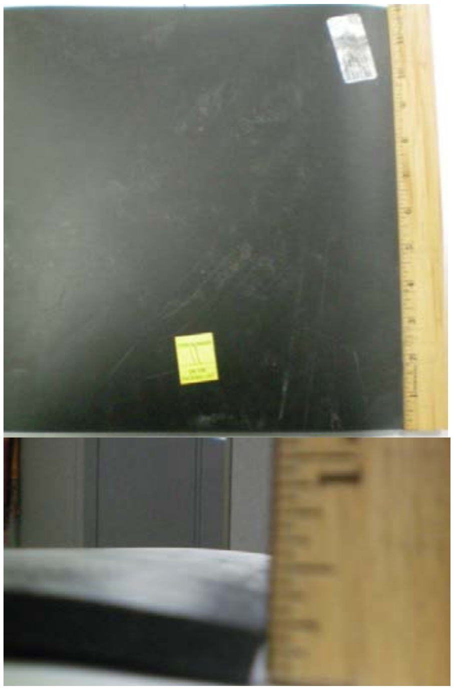


Figure B-1. R2 Butyl Rubber.

Figure B-2. R3 Buna-N Rubber.

Figure B-3. R5 EPDM Rubber.

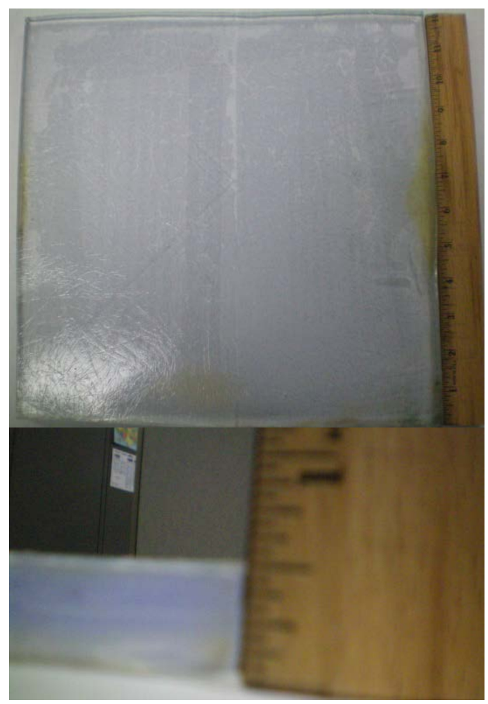


Figure B-4. R6 Gel Rubber.

Figure B-5. R7 Gum Rubber.

Figure B-6. R8 Hypalon Rubber.

Figure B-7. R9 Natural Rubber (Neoprene).

Figure B-8. R10 Nitrile Rubber.

Figure B-9. R11 PVC Rubber.

Figure B-10. R12 Santoprene Rubber.

Figure B-11. R13 SBR Rubber.

Figure B-12. R14 Vinyl Rubber.

Figure B-13. R15 Viton Fluoroelastomer Rubber.

Figure B-14. Material R4 Bowling Ball Penetration.

APPENDIX C

IMPULSE GRAPHS

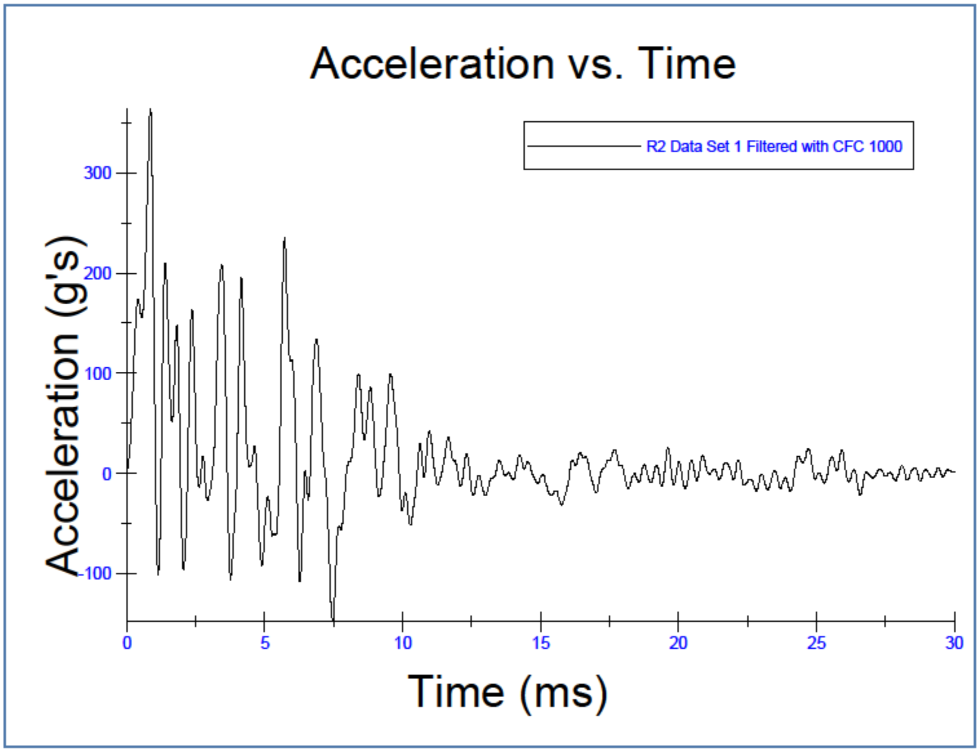


Figure C-1. Material R2 Impulse Graph.

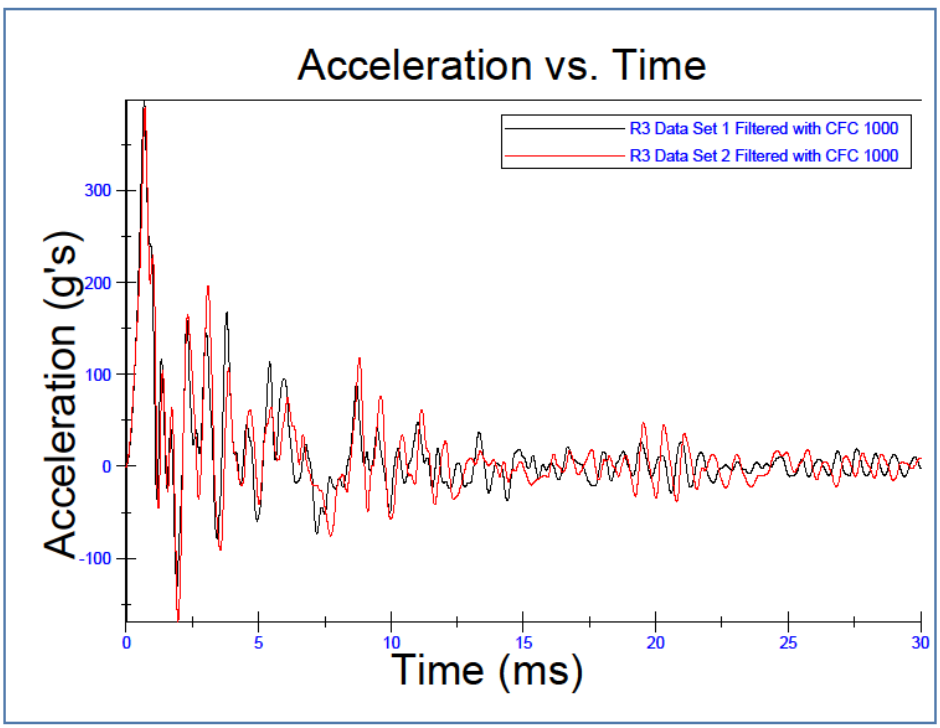
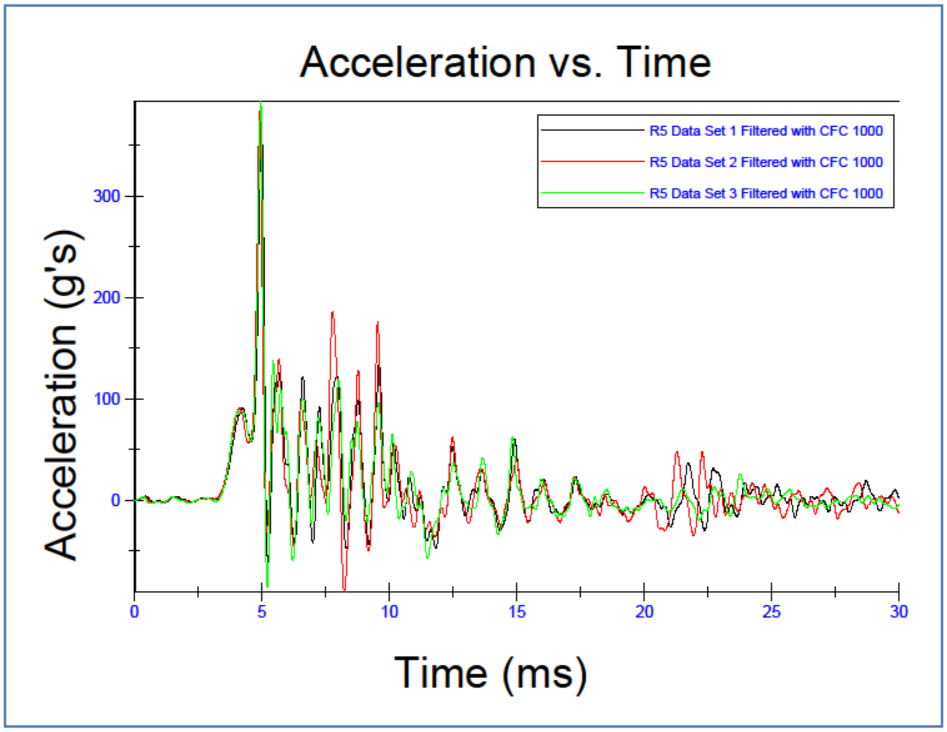
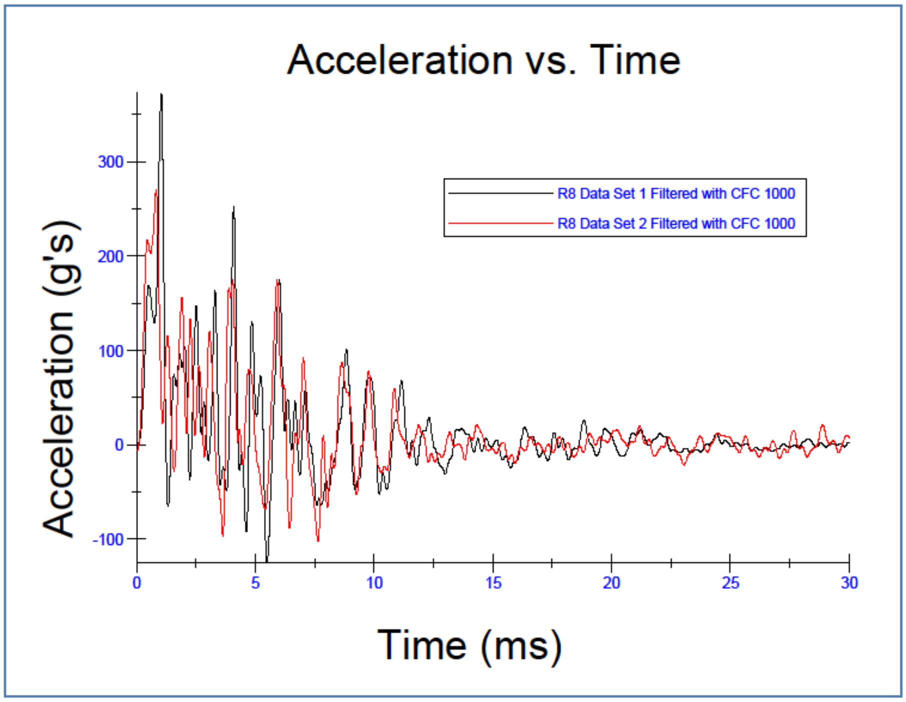


Figure C-2. Material R3 Impulse Graph.



<u>Figure C-3.</u> Material R5 Impulse Graph.



<u>Figure C-4.</u> Material R8 Impulse Graph.

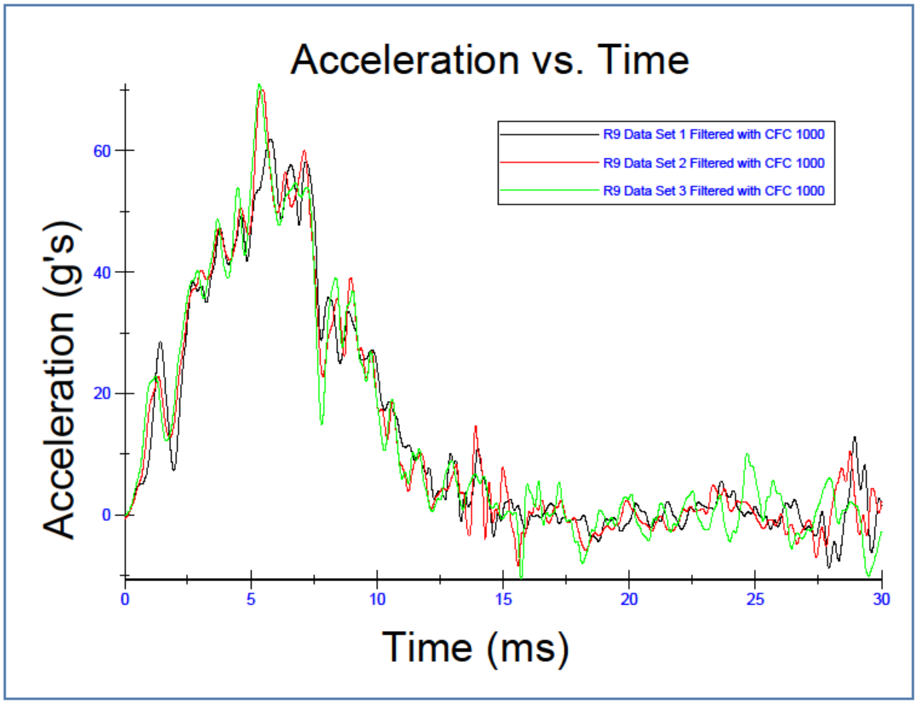


Figure C-5. Material R9 Impulse Graph.

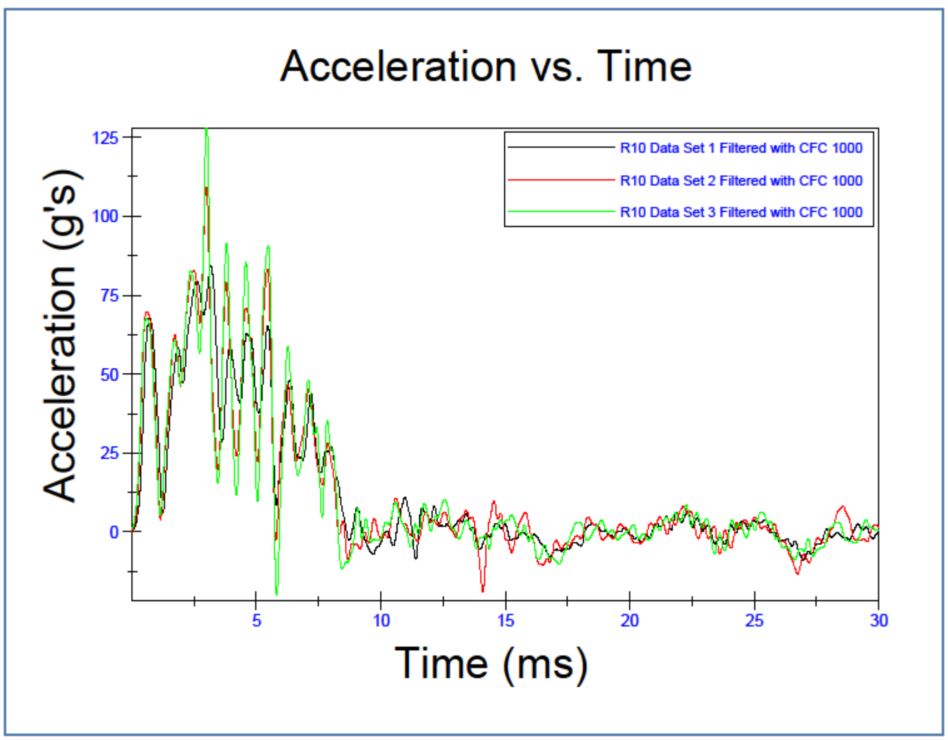


Figure C-6. Material R10 Impulse Graph.

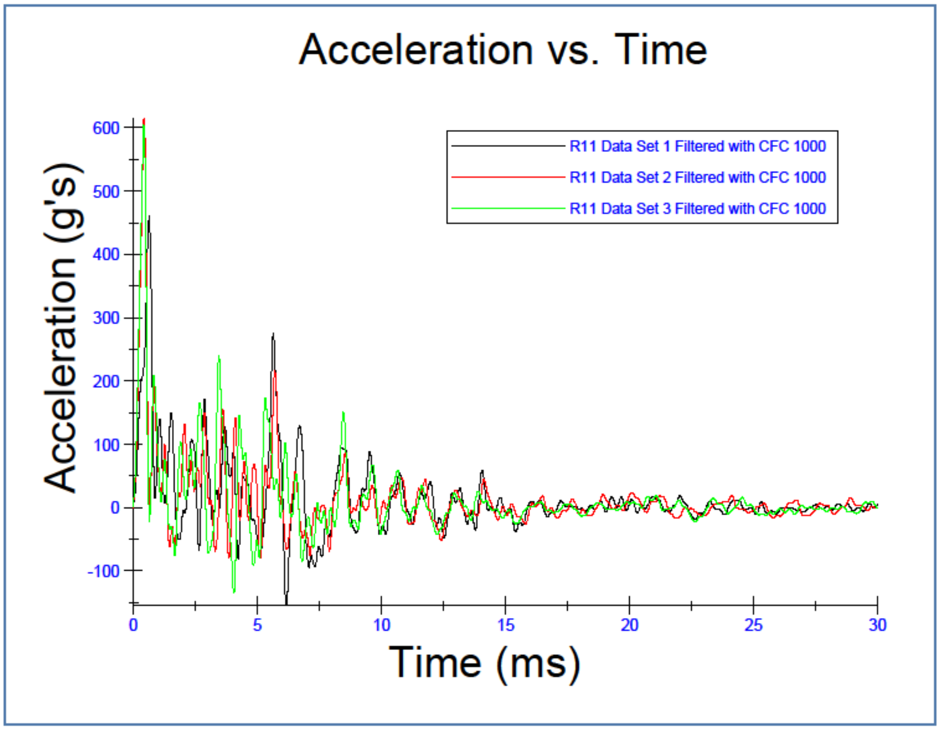


Figure C-7. Material R11 Impulse Graph.

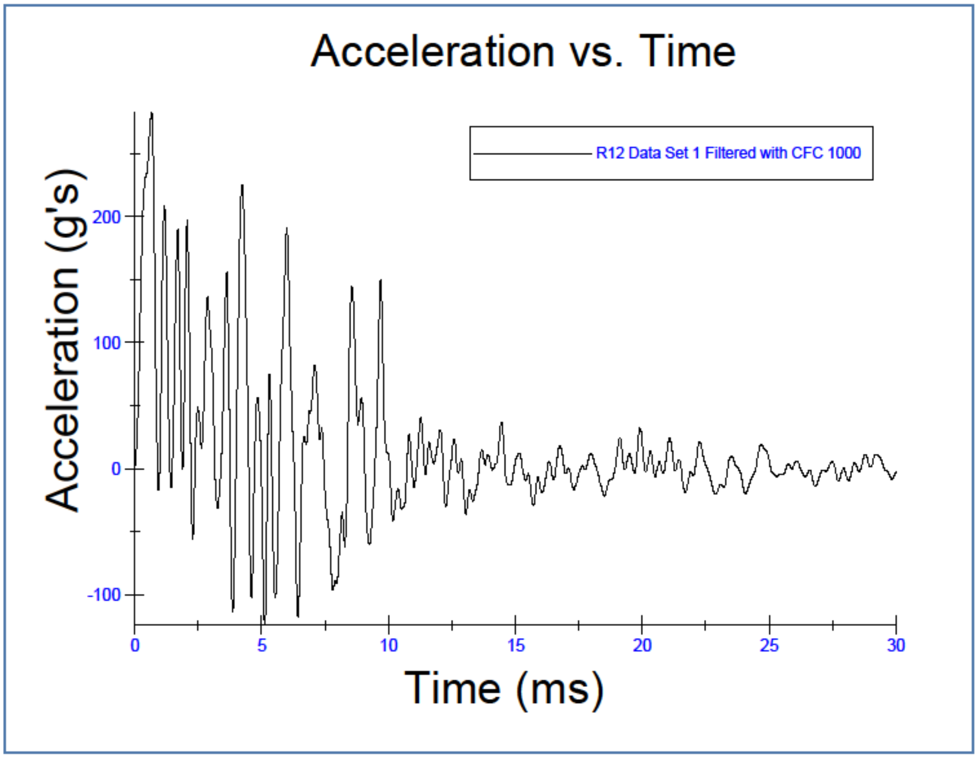


Figure C-8. Material R12 Impulse Graph.

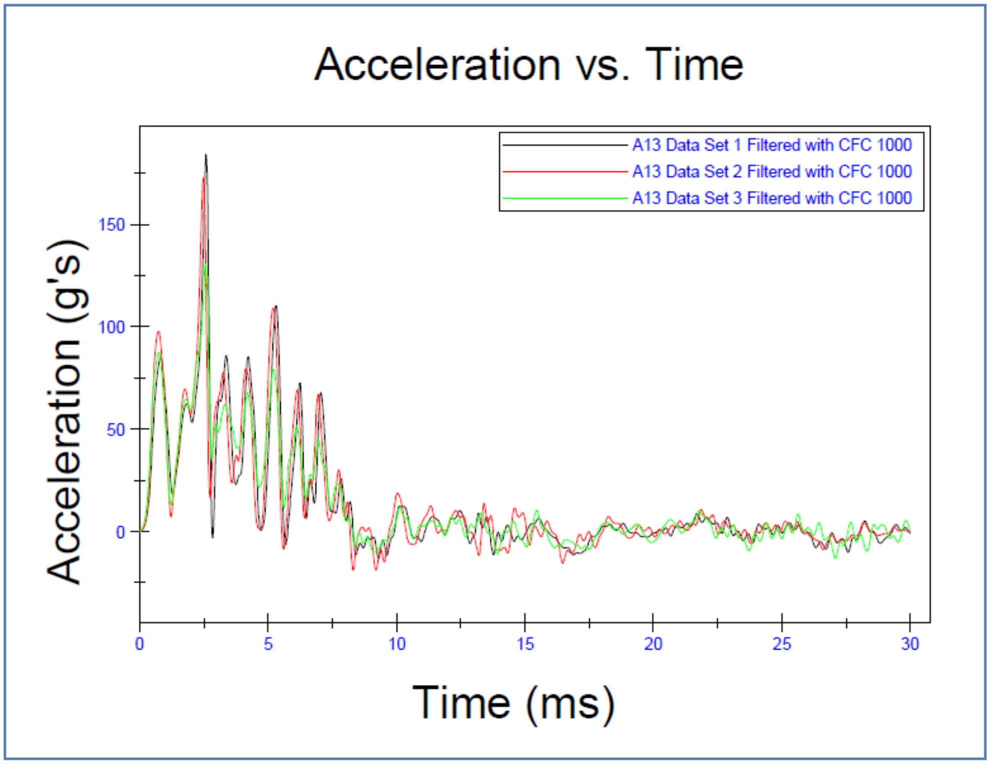


Figure C-9. Material R13 Impulse Graph.

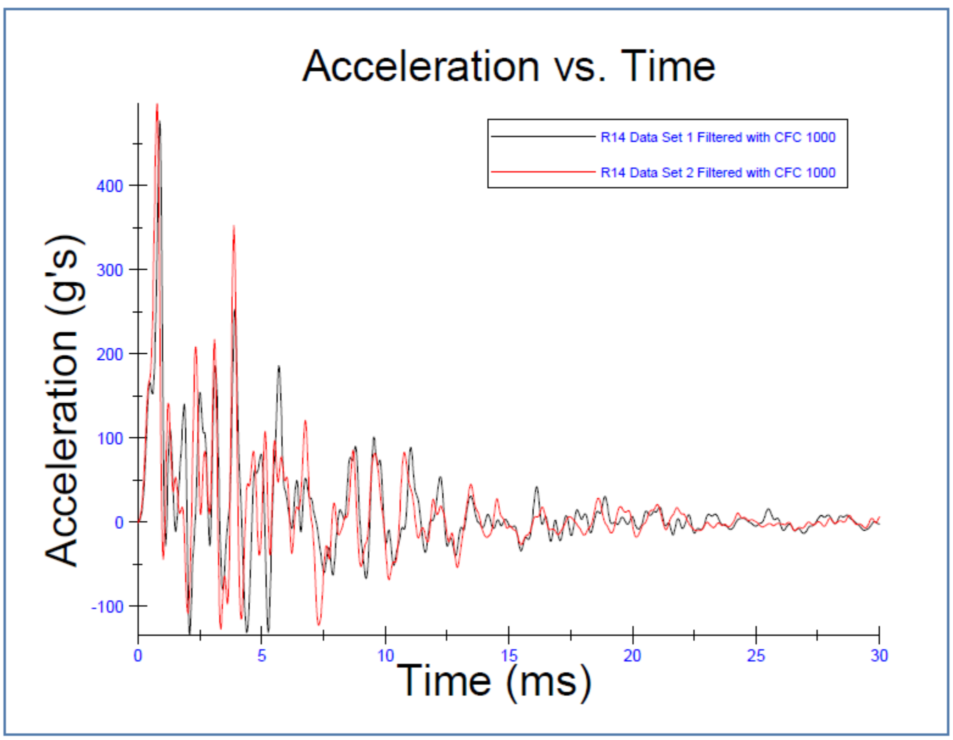


Figure C-10. Material R14 Impulse Graph.

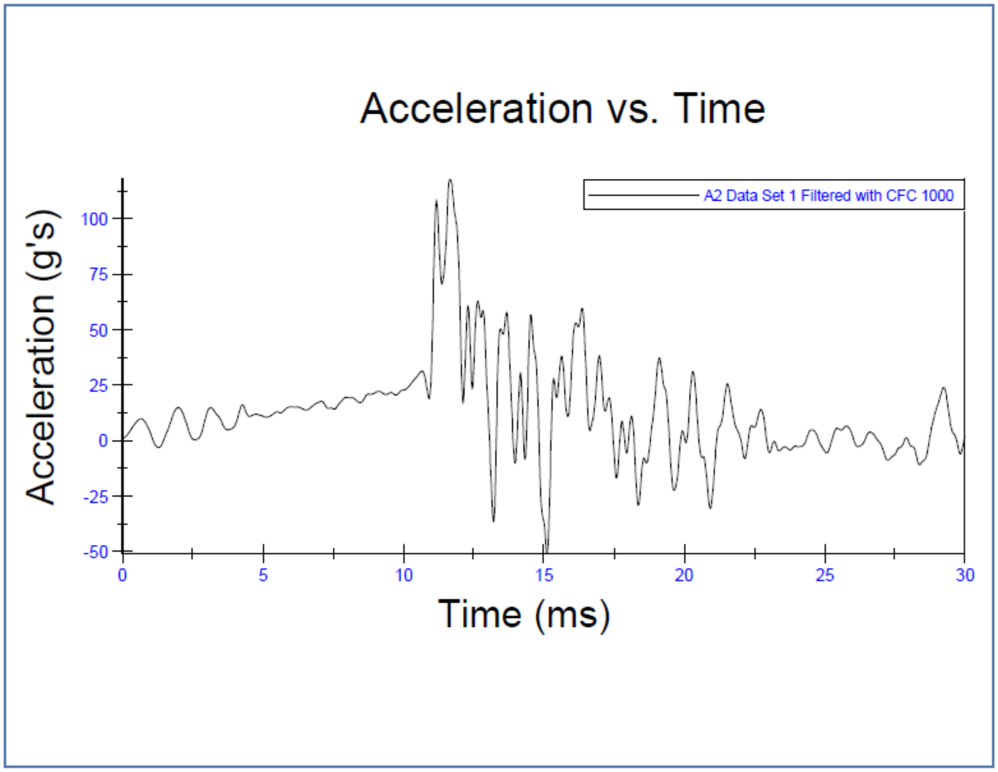


Figure C-11. Material A2 Impulse Graph.

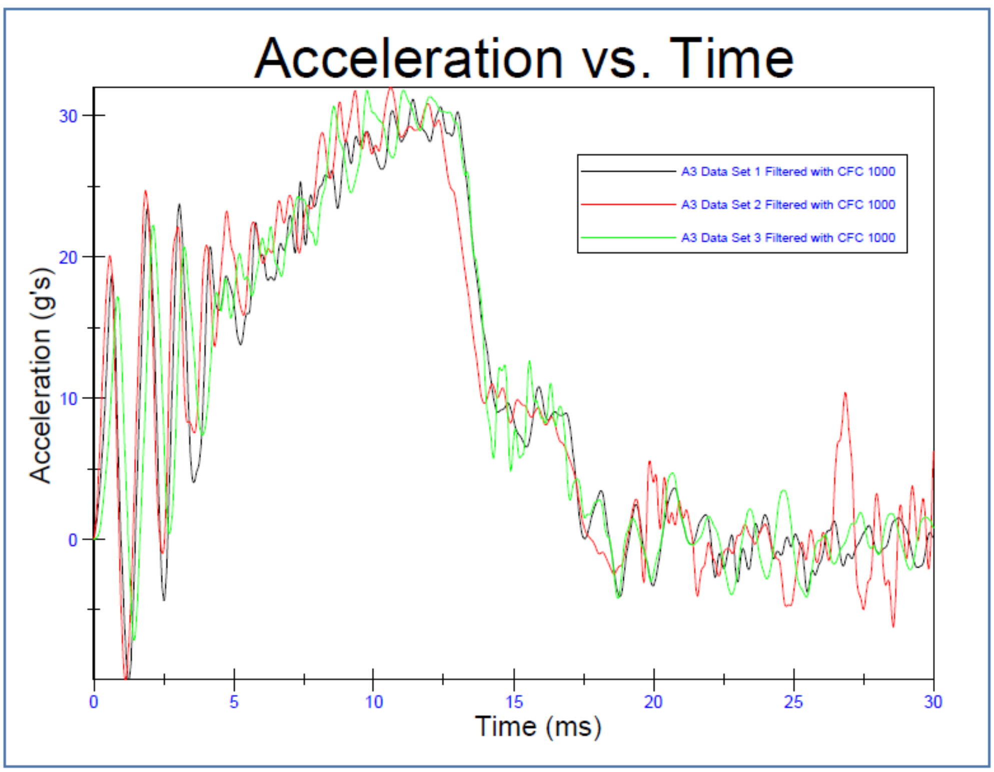


Figure C-12. Material A3 Impulse Graph.

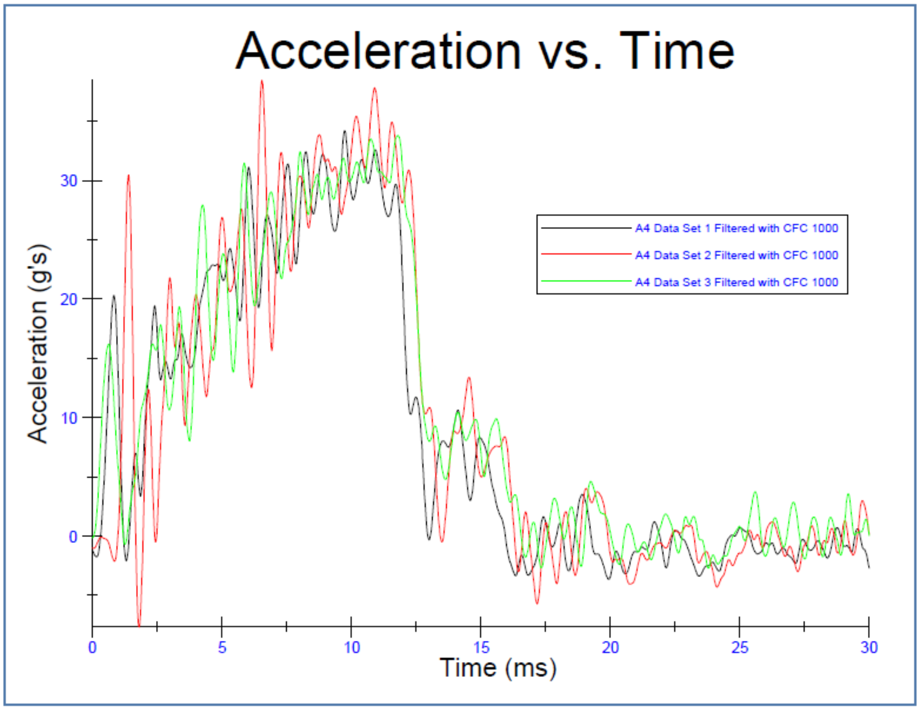


Figure C-13. Material A4 Impulse Graph.

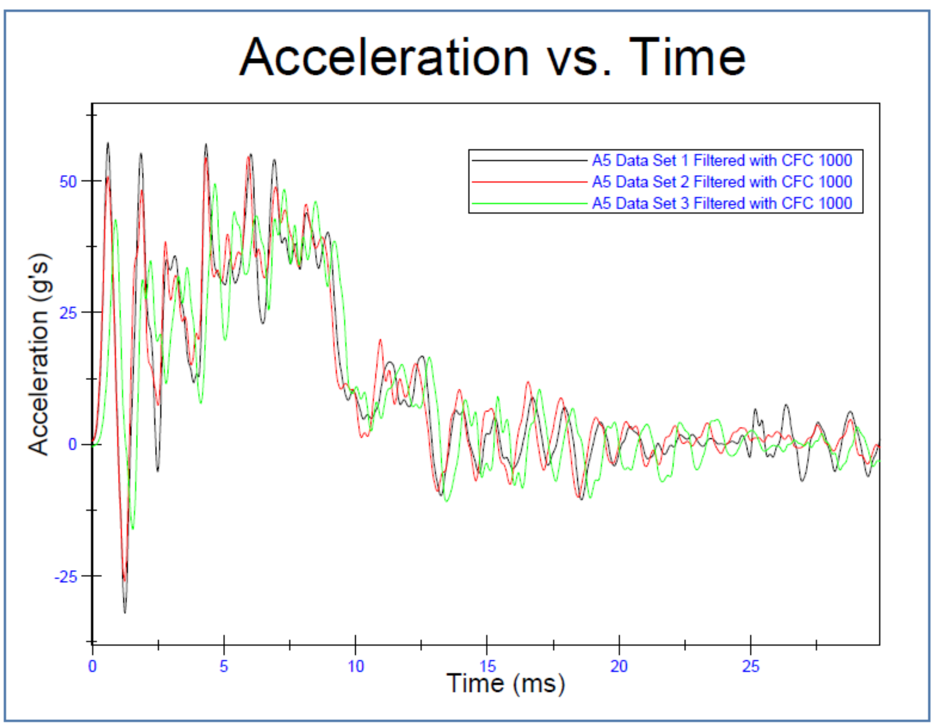


Figure C-14. Material A5 Impulse Graph.

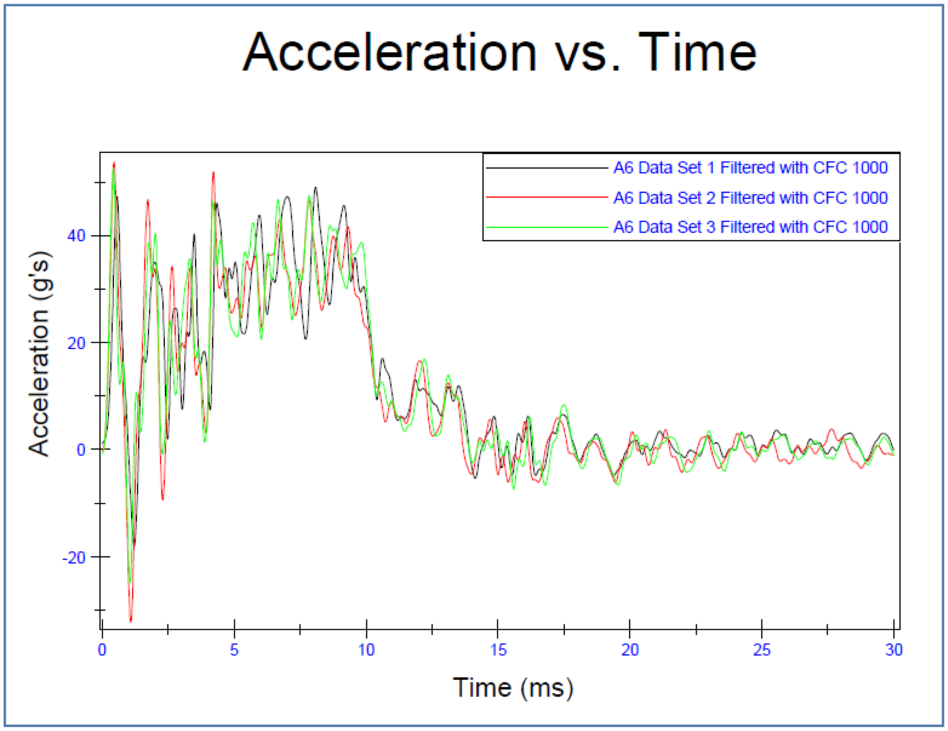


Figure C-15. Material A6 Impulse Graph.

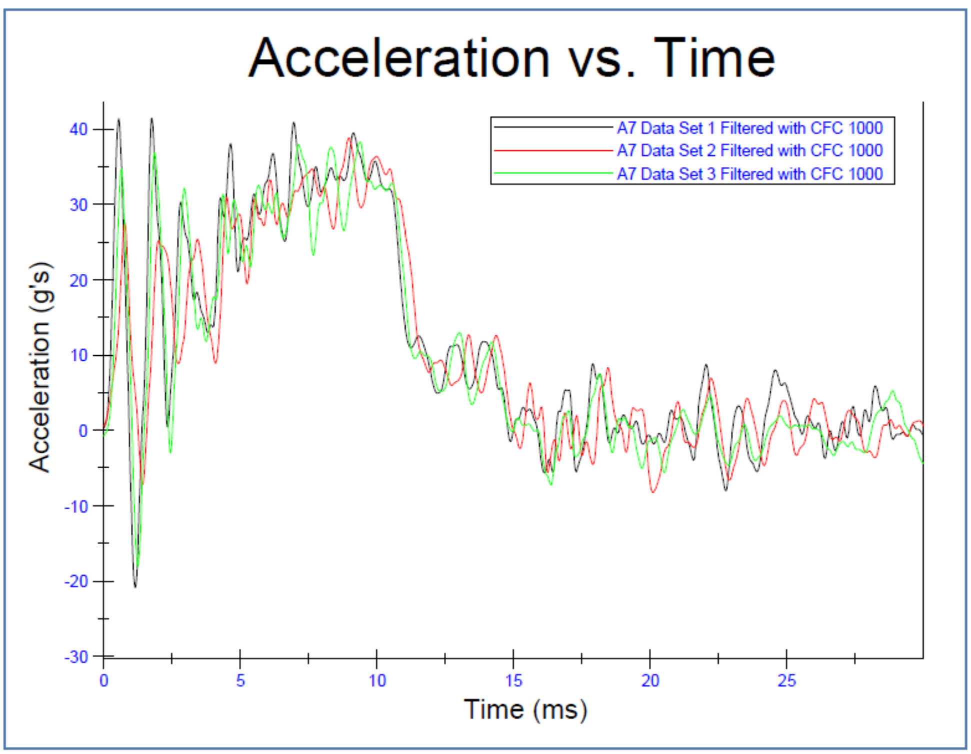


Figure C-16. Material A7 Impulse Graph.

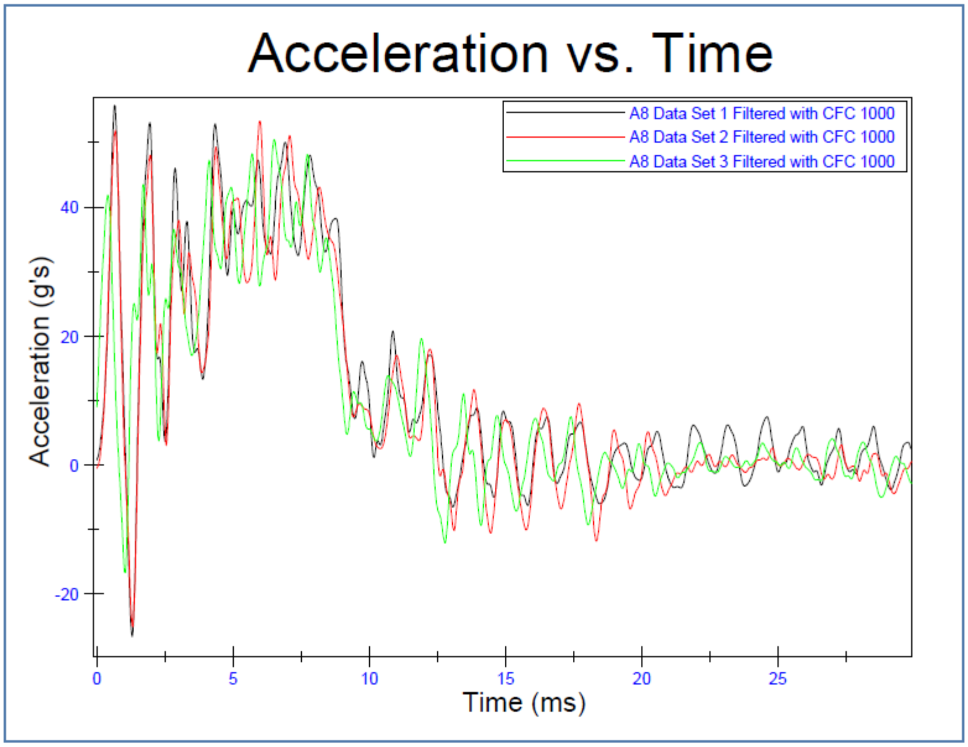


Figure C-17. Material A8 Impulse Graph.

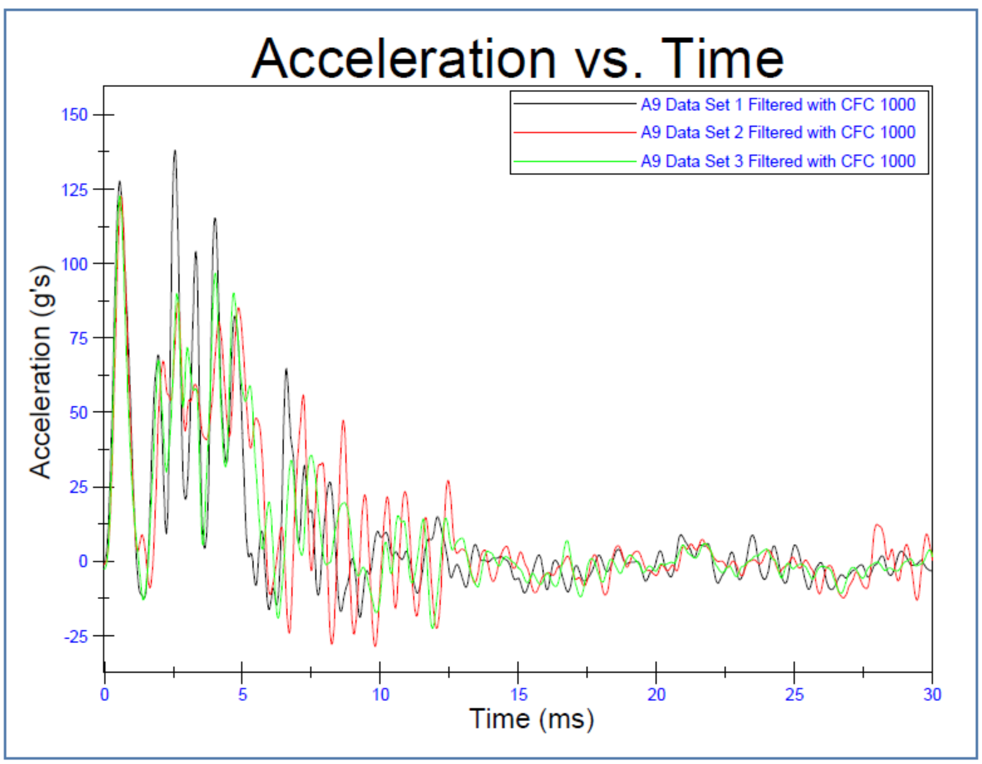


Figure C-18. Material A9 Impulse Graph.

APPENDIX D

ALUMINUM HONEYCOMB POST IMPACT PICTURES

Figure D-1. Material A1 Post Impact.

Figure D-2. Material A2 Post Impact.

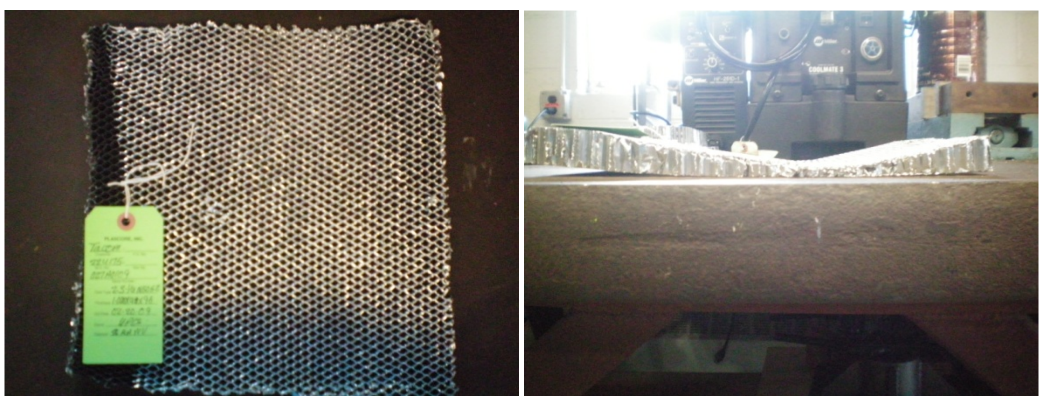


Figure D-3. Material A3 Post Impact.

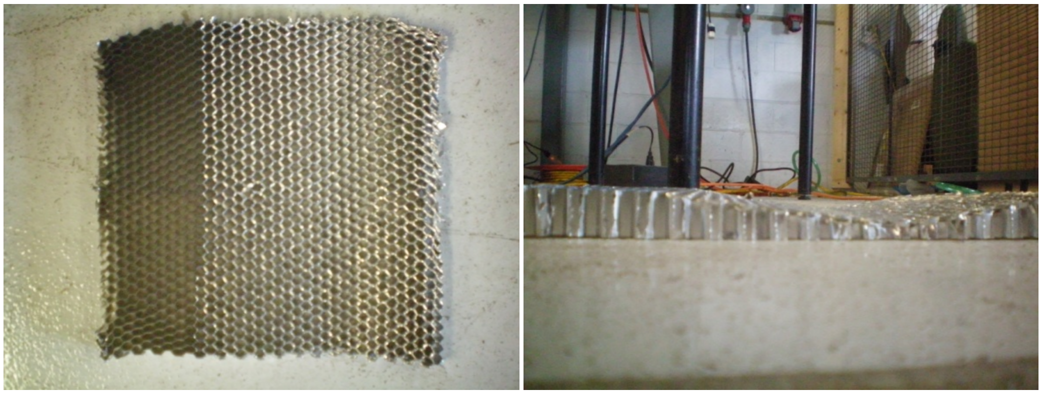


Figure D-4. Material A4 Post Impact.

Figure D-5. Material A5 Post Impact.

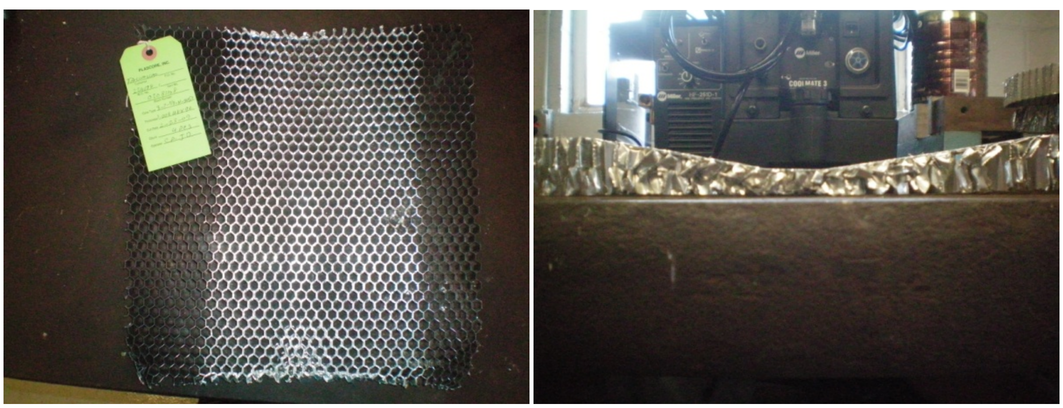


Figure D-6. Material A6 Post Impact.

Figure D-7. Material A7 Post Impact.

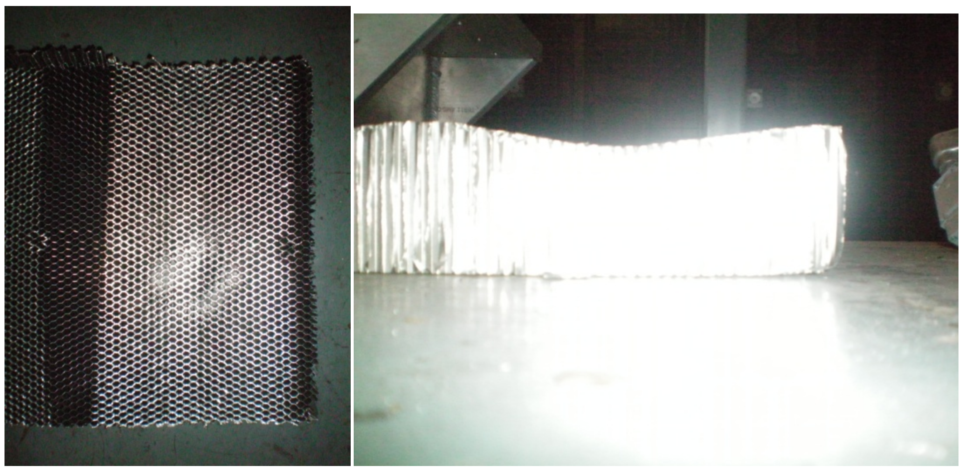


Figure D-8. Material A8 Post Impact.

Figure D-9. Material A9 Post Impact.

APPENDIX E

OTHER INFORMATION

Vision Research Phantom Viewer

The Phantom Viewer by Vision Research is software that was used to record, view, and analyze the high speed video files. The software is described as follows, by the Vision Research website,

> "This software allows you to view Phantom Cine files and can be used as a demo of standard Phantom software. You can convert cine files to other file formats. And, you can also do image processing."

Data Acquisition Information

The Data Acquisition System (DAS), sensors, and software (version 1.4.00) used in collecting and managing the data is created and owned by Diversified Technical Systems, Inc. (DTS), who designs and manufactures data acquisition systems and sensors. The information gathered was from a SLICE system. SLICE is described as the following, by the DTS website,

> "SLICE is a modular data acquisition system with unmatched flexibility, technology and reliability in an unbelievably small size. … The Base SLICE contains the microprocessor, memory and all control circuits for managing multiple 3-channel slices. This modular systems allows users to create customized data acquisition systems with different channel counts and sensor inputs. A simple interface provides power, trigger and communication signals for chaining multiple SLICE stacks or connecting to your PC."

Figure E-1. DTS SLICE.

Impulse

To replicate an impulse, similar to those seen in vehicle crashes or blasts, the drop platform is raised to a specific height and different configurations of hexagonal aluminum honeycomb are used until a suitable pulse match is found. A simple impulse graph is shown below.

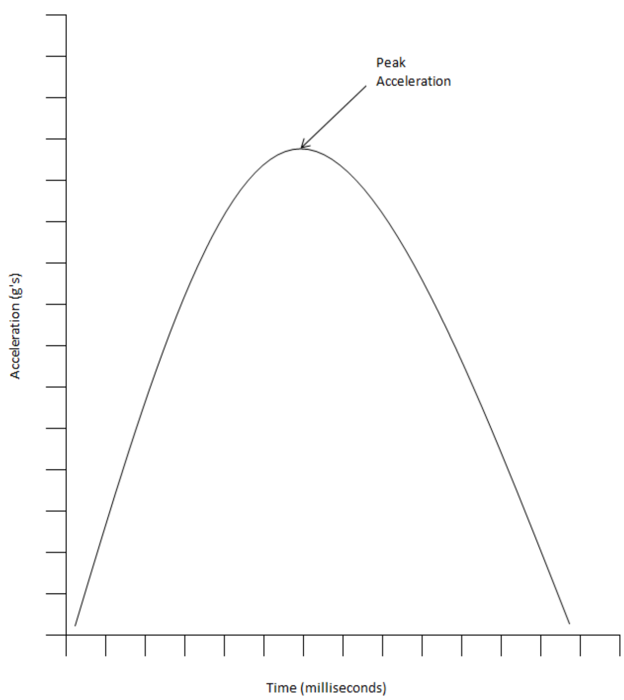


Figure E-2. Simple Impulse Graph.

The peak acceleration is the maximum number of g's an accelerometer experiences at a certain point in time. This curve, as evaluated for each aluminum honeycomb sample test material, was used as guidance for comparison of rubber sample test materials.

Filtered Data

Data received from an event is raw data, data that has simply been collected and not processed. Filtering data is taking raw data and processing it so that any data that is not within the filter scope is removed. This gives a better picture of an event. For example metal on metal contacts create chatter, or vibrations, in a data recording system that have little to do with the event and more to do with the metal contacts. This unrelated raw data needs to be removed to see a better picture of the event data.

APPENDIX F

ABET PROGRAM OUTCOMES

PROGRAM OUTCOMES
MECHANICAL ENGINEERING
(Updated for 2008/09 Academic Year)

Upon graduation, students receiving the Bachelor of Science in Mechanical Engineering Degree from Kettering University will have the following knowledge, skills, and abilities:

A. An ability to apply knowledge of mathematics, science and engineering.

   My thesis involved material science and physics calculations. All of this applied knowledge I have gained in mathematics, science, and engineering.

B. An ability to design and conduct experiments, as well as to analyze and interpret data.

   The project involved designing a test setup, conducting multiple experiments, and then analyzing and interpreting the results to form a conclusion.

C. An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.

   The project did not involve many of these aspects due to the isolation of the project. It was one piece of equipment. The project did somewhat involve a process (testing) with environmental constraints, environmental awareness of the effects of the materials.

D. An ability to function on multi-disciplinary teams.

   The project required work with other non-team individuals but at no point was it a collaborative effort between multiple teams.

E. An ability to identify, formulate, and solve engineering problems.

   The project forced an approach that identified simple engineering problems that were difficult to formulate and correlate but rather easy to solve.

F. An understanding of professional and ethical responsibility.

   The project demanded a professional and ethical responsibility due to implications of use of the structure.

G. An ability to communicate effectively.

The project demanded communication with others and quickly proved necessary to the completion of the project.

H. The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.

As previously stated there were limited involvement of these impacts but with regards to environmental impacts a Mechanical Engineering coursework provided much insight.

I. A recognition of the need for, and an ability to engage in lifelong learning.

The project provided this insight because even with all of the knowledge gained through a Mechanical Engineering degree there were elements that I needed to educate myself on before concluding certain steps due to my unfamiliarity.

J. A knowledge of contemporary issues.

The project addressed issues currently surrounding decelerative materials.

K. An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

The project called for the use of software to interpret data recorded from the Data Acquisition System (DAS) and therefore I used techniques, skills, and modern engineering tools.

L. Familiarity with statistics and linear algebra.

This project did not involve statistics or linear algebra due to the uniqueness of the equipment, as previously stated.

M. A knowledge of chemistry and calculus-based physics with a depth in at least one of them.

This project involved simple physics covered in Physics I.

N. An ability to model and analyze inter-disciplinary mechanical/electrical/hydraulic systems.

The project did not involve any modeling due time and budgetary constraints.

O. An ability to work professionally in the area of thermal systems including the design and realization of such systems.

   The project did not involve thermal systems because none were involved with the equipment.

P. An ability to work professionally in the area of mechanical systems including the design and realization of such systems.

   The project involved the realization of a mechanical system that was just recently created.