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Shock Tube Response of Polycarbonate and Polyvinyl Chloride Exposed to UV Radiation for Use in Military Application

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SHOCK TUBE RESPONSE OF POLYCARBONATE AND POLYVINYL CHLORIDE EXPOSED TO UV RADIATION FOR USE IN MILITARY APPLICATION

By

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A thesis submitted to the faculty of The University of Mississippi in partial fulfillment of the requirements of the Sally McDonnell Barksdale Honors College.

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Approved By

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DEDICATION

This thesis is dedicated to everyone who guided and encouraged on my journey to completing this research and my Bachelor's degree. In particular, my mother and father Mr. and Mrs. Scott and Deanna Jones that continue to encourage me every step of the way and teach me to purse my dreams. I would also like to dedicate this thesis to Dr. Damian Stoddard and Mr. Matt Lowe who have made a large impact on my learning and engineering education. Thank you.

ACKNOWLEDGEMENTS

I would like to acknowledge Dr. Damian Stoddard for guiding and training me to think critically about the completion of this thesis and to go the extra mile in all parts of this research. I would also like to acknowledge my appreciation for my second and third thesis readers, Dr. Wen Wu and Dr. Raj Rajendran. Additionally, I would like to acknowledge Mr. Matt Lowe, Mechanical Engineering Machine Shop Supervisor, for modification to experimental setups as well as preparation of samples. Lastly, I would like to acknowledge the group of fellow undergraduate researches that assisted during material testing.

ABSTRACT

As today's society becomes increasingly more conscious of finding alternative ways to power our vehicles, research surrounding solar-charged military vehicles is on the rise. With this endeavor comes an engineering feat of discovering the proper material that is cost-effective, wear-resistant, and strong enough to withstand the harsh elements and potentially large impacts that these military-grade vehicles may encounter.

This research tested two types of materials in a shock tube to simulate their behavior in a dynamic impact. These materials were polycarbonate and polyvinyl chloride, more commonly known as PVC. In addition to control samples of both of these materials, samples of each were subjected to accelerated UV radiation to determine the degradation effects on both.

Experimental analysis was conducted using high-speed photography and Digital Image Correlation. Various relationships such as load versus displacement, displacement versus time, and deformation energy versus time were analyzed. Additionally, the total deflection, specific energy, and acceleration were determined and compared for each material. The primary results concluded that the unexposed polycarbonate performed the best in all categories, followed by the exposed polycarbonate, the unexposed PVC, and the exposed PVC.

This study provides a critical base for future iterations in which more materials are studied in a similar manner and compared to the ones discussed.

PREFACE

This thesis was written in accordance with the standards of the Sally McDonnell Barksdale Honors College at the University of Mississippi. As I look ahead to all that is to come, I will also look back fondly at my time as an Honors student and remember that I am standing on the shoulders of giants.

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LIST OF ABBREVIATIONS

PVC	Polyvinyl Chloride
PC	Polycarbonate
PVC_UV	Polyvinyl Chloride Subjected to Ultraviolet Radiation
PC_UV	Polycarbonate Subjected to Ultraviolet Radiation
DIC	Digital Image Correlation

CHAPTER 1: INTRODUCTION

This study aims to gain a thorough understanding of dynamic response of controlled Polyvinyl Chloride (also known as PVC) and Polycarbonate by dynamically testing samples in a shock tube. Additionally, the objective is to determine the effect of UV radiation on both of these materials' dynamic characteristics. The primary goal is to determine how the plastics will uphold in the application to protect the fragile elements of solar cells on the exterior of solar-powered military-grade vehicles. New research suggests that "solar charging... could extend a vehicle battery's life 3-to-5 times, saving the Army about $17 million per year" [1]. Replacing vehicles powered by fossil fuels with solar-powered ones is a cost-effective and sustainable option. Understanding the material properties of PVC and polycarbonate is significant for reducing the life cycle cost of materials and increasing the overall effectiveness and safety of a given structure.

Depending on initial material properties and exposure to elements, different strength and durability properties may be displayed. While quasi-static load testing or the use of a low-velocity impact machine is desired in applications where a material will be compressed at a low speed, dynamic load testing is instrumental in cases where deformation happens quickly. Examples of this loading category include compression by a crash, explosion, or extreme excitation such as an earthquake. The purpose of this experiment is to examine various candidate plastics for use on military-grade vehicles. One example of the damage that military vehicles may suffer while in use can be seen in Figure 1 below. When considering the significant impact these vehicles see in training and combat, dynamically testing the materials in question will yield the most accurate results.

Figure 1. Damage to Military Vehicle as a Result of Bullets and Shell Fragments (Alamy, 2019)

A shock tube is one of the many ways to simulate dynamic loading conditions. It was invented in 1899 by French scientist Pierre Vieille [2] and allows one to measure parameters such as load-displacement and deflection, thus providing a method for studying materials' behavior at high loading rates. Deflection is defined as the degree to which a material is displaced under a load. Determining and comparing the relationship between deflection and time for various materials is crucial to designing impact-resistant systems.

Solar UV radiation negatively affects the mechanical properties of organic materials, such as plastics. The service lifetimes of these materials greatly depend on their application and resistance to degradation under UV radiation [3]. Understanding which materials are able to best maintain their desirable qualities over time allows engineers to build the most cost-effective and safe structures. This is particularly important when considering structures such as military vehicles that have an increased risk of dynamic loading or impact while also having a large amount of UV exposure.

A study by Tcherbi-Nartheh, Hosur, and Jeelani examined the mechanical and thermal properties of carbon/epoxy nanoclay composites that were exposed to UV radiation. The samples were exposed to 15 days of UV radiation using the QUV/SE accelerated weathering chamber which was equipped with 340nm fluorescent lamps and an irradiance generation of 0.68 W/m^2 in accordance with ASTM G-154. After the degradation period of 360 hours, these materials were dynamically tested and their characteristics were analyzed against control samples. The study revealed that the modulus of the conditioned samples increased while the strength decreased when compared to their unconditioned counterparts. [4]

A study by Xuan, Sun, and Wei aimed to understand the compressive mechanical behavior of polyvinyl chloride (PVC) under dynamic loading conditions. The samples were subjected to both quasi-static compression tests and dynamic compression tests. After dynamically testing the PVC samples in the Split Hopkinson Pressure Bar, it was found that the deformation resistance of the PVC at a high strain-rate was significantly higher than that of a low strain-rate. This study gives an initial indication that PVC may have desirable characteristics for use in a high-impact scenario. [5]

Curtis Bartosz et al. conducted a study on the degradation of polymers by UV light exposure. This study aimed to determine a method of calculating an acceleration factor between samples that are aged both naturally and artificially under UV lamps. The study explains that the absorption of a UV photon by polycarbonate molecules leads to a breakdown of the molecules into small pieces. This may result in the aged material being more brittle. The study also states that it is generally accepted that photo-oxidation of polycarbonate is triggered by photons of 350nm or less, meaning that the accelerated weathering chamber should match the solar spectrum below 350nm as well. Samples were exposed to UV lamps at time intervals from 0 hours to 1266 hours, with samples removed each time for intermediate testing. The test results concluded a 23% drop in the polycarbonate samples' flexural toughness between the control and final samples. [6]

CHAPTER 2: MATERIALS AND METHODS

2.1 Material Description

Materials tested include polyvinyl chloride (PVC) and polycarbonate samples obtained from McMaster-Carr. Unconditioned and UV conditioned samples of both materials were tested at a burst pressure of 400 psi.

Polycarbonate is often used as a "glazing to protect glass and other fragile elements from impact" [7]. It is known for its transparent nature, which makes it a strong candidate for covering the portion of solar cells that require light to reach. Additionally, the strength characteristics would also make this plastic ideal for use on other parts of the cell structures that do not necessarily require direct sunlight. With this knowledge, one forms an initial hypothesis that Polycarbonate may be a good plastic for use as solar-cell protection.

Polyvinyl chloride (PVC) is also considered for use on the exterior of military vehicles due to its resistance to sunlight, weathering, and flames [8]. PVC is also economically friendly due to its ease of attainability, in addition to being durable and having excellent tensile strength

[9]. These are desirable characteristics considering the harsh environments that the potential plastic is likely to be exposed to on these vehicles.

2.2 Conditioning

Three samples of polyvinyl chloride and three samples of polycarbonate were subjected to UV radiation using the QUV/SE accelerated weathering chamber. This weathering chamber is an effective and quick way to simulate long-term UV exposure. The samples were exposed to constant radiation for 360 hours. In accordance with ASTM G-154 and using the knowledge from previous studies stated above, the fluorescent lamps had a wavelength of 340 nm and created irradiance of 0.68 W/ m^2. The machine was set to a temperature of 60 ºC. These variables were determined based on a previous UV radiation study conducted by Tcherbi-Nartheh, Hosur, and Jeelani [4]. The samples were placed in fixtures as seen below in Figure 2 to be held securely in the chamber.

Figure 2. Untested Samples in Secure Chamber Fixtures

2.3 Shock Tube Theory

The purpose of a shock tube is to simulate a shock wave event on an engineering scale [10]. This is done through the generation of a shock wave using a section of high-pressure 'driver' gas and a section of low-pressure 'driven' gas. These sections are separated by high speed valve [11]. Gas is added to the driver side until the diaphragm bursts and a shock wave travels at or above the speed of sound towards a sample. When the shock wave from the driver side contacts the driven gas, pressure is released at the diaphragm and an expansion wave reflects back to the driver section. At the same time, a contact surface is created that initiates shock wave propagation. This shock wave impacts the sample and is carried to the end of the low-pressure section to the closed endwall of the shock tube [12]. Relationships such as deflection versus time, load versus deflection, and backface deformation energy versus time can be calculated and used to evaluate the samples' properties. A schematic of the aforementioned process can be seen below in Figure 3 [12].

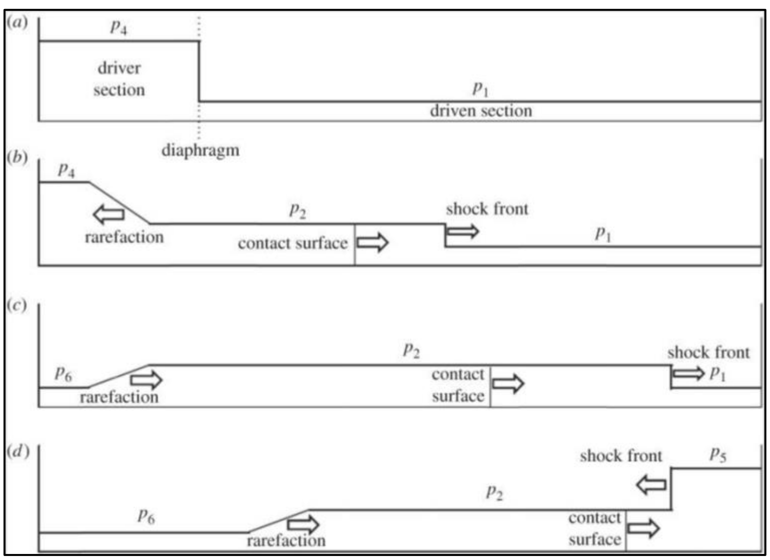

Figure 3. Shock Tube Operation Schematic [12]

It is also important to mention that the properties of gas that change throughout the experiment include the particle velocity u, the pressure p, the sound velocity c, the density ρ, the specific volume τ, and the specific internal energy e [11]. These properties change based on the three sections as seen below in Figure 4.

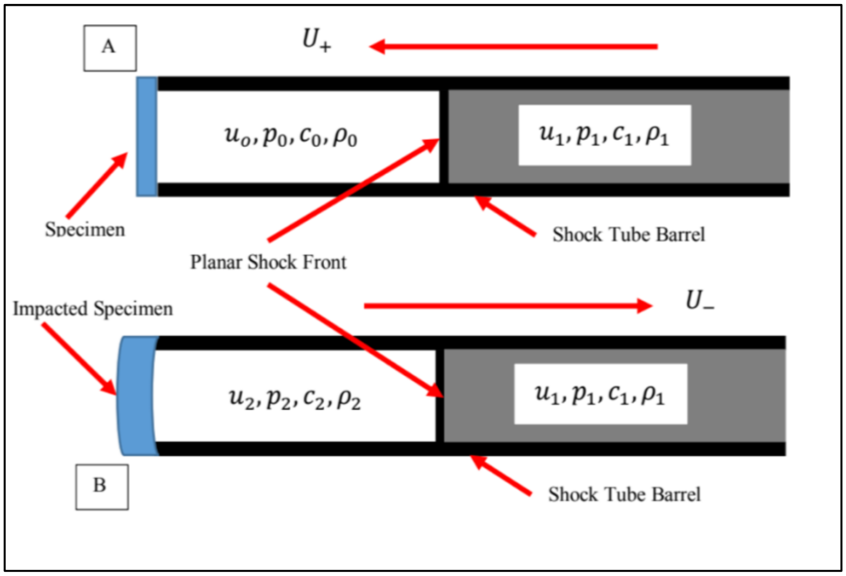

Figure 4. Incident and Reflected Shock Front Schematic [11]

From sections 0, 1, and 2 above, the energy is divided into the internal energy, the translational energy, and the work done by the gas over time. These equations are defined as,

$$dE_{Work\ Done} = p(t) * S * |u(t)|dt \qquad \textit{Equation 1.}$$

$$dE_{internal} = \frac{p(t)*S*|u(t)|}{\gamma-1}dt \qquad \textit{Equation 2.}$$

$$dE_{translational} = \frac{1}{2}\rho(t) * S * \ |u(t)|^3 dt \qquad \textit{Equation 3.}$$

where γ is the adiabatic exponent of the gas and S is the cross sectional area [11]. The integration of these equations allows for the incident and remaining energy to be calculated. While the area and pressure profile are known during experimentation, the velocity, density, and sound speed are calculated using the following equations,

$$\rho\tau = 1 \qquad \textit{Equation 4.}$$

$$e = \frac{1}{\gamma - 1} p\tau \qquad \textit{Equation 5.}$$

$$\rho c^2 = \gamma p \qquad \textit{Equation 6.}$$

$$p = A\rho^{\gamma} \qquad \textit{Equation 7.}$$

where A represents the reversible process of the initial state of gas in an adiabatic process [11]. When combining Equation 4 with the conservation of mass and momentum, one obtains the following equations,

$$(\tau_1 + \tau_0)(p_1 - p_0) = v_0^2 - v_1^2 \qquad \textit{Equation 8.}$$

$$\frac{(p_0 - p_1)}{(\tau_0 - \tau_1)} = \rho_0 v_0 = \rho_1 v_1 \qquad \textit{Equation 9.}$$

$$\frac{(p_1 - p_0)}{(\rho_1 - \rho_0)} = v_o v_1 \qquad \textit{Equation 10.}$$

where v is the particle velocity relative to the planar shock front [11]. Using Equation 8 in combination with the conservation of energy, one can obtain the Hugoniot relationship as seen in Equation 11 below, which is useful for linking 'the density and pressure in a stream of gas before a shock with the density and pressure after the shock' [13].

$$H(\tau, p) = e_1 - e_0 + \frac{1}{2}(\tau_1 - \tau_0)(p_1 - p_0) = 0 \qquad \textit{Equation 11.}$$

In the above equation, e and τ are the specific energy and the specific volume, respectively. These values cannot be obtained in this experiment, thus the Hugoniot equation must be modified with only parameters that can be found using the shock tube. Modification of equations listed above yields the following relationships:

$$\frac{p}{p} = \frac{\tau_0 - \mu^2\tau_1}{\tau_1 - \mu^2\tau_0} = (1+\mu^2)M_0^2 - \mu^2 = (1+\mu^2)M_1^2 - \mu^2 \qquad \textit{Equation 12.}$$

where $\mu^2 = \frac{(\gamma-1)}{(\gamma+1)}$ and M is the Mach number [11].

It is also important to mention the relationship between the adiabatic exponent of the gas, velocity of the shock fronts U+ and U-, particle velocities and sound speed. The appropriate equations that define the relationship between these parameters can be seen in Equations 13 and 14.

$$(1-\mu^2)(U_+ - u_0)^2 - (u_1 - u_0)(U_+ - u_0) = (1-\mu^2)c_0^2 \qquad \textit{Equation 13.}$$

$$(1-\mu^2)(U_+ - u_1)^2 - (u_0 - u_1)(U_+ - u_1) = (1-\mu^2)c_1^2 \qquad \textit{Equation 14.}$$

A samples' deformation energy can be obtained using information gathered from high speed camera images, including the sample deflection and the pressure profile. By integrating the pressure-deflection curve as seen in Equation 15 below, one can determine the deformation energy [11].

$$E_{deformation} = \oint_{S_{shock\,tube}} \left(\int p_2(t)\,dl_{deformation}\right) dS \qquad \textit{Equation 15.}$$

2.4 Experimental Setup

This study was conducted in the research lab at the University of Mississippi, where the shock tube is housed. The manufacturer of the shock tube used in this research is Srushti Engineering Innovations Private Limited. The setup consisted of a driven section, a driver section, a diaphragm separating the two, and pressure gauges attached to both the driven and driver sections. The pressure transducers used were Kulite model HKS-HP-375-5000SG, and the box they were attached to was a Kulite model KSC-2. The sample was placed in the test section chamber. A photo of the University of Mississippi shock tube can be seen in Figure 5 and a schematic of the labeled machine parts can be seen in Figure 6.

Figure 5. University of Mississippi Shock Tube

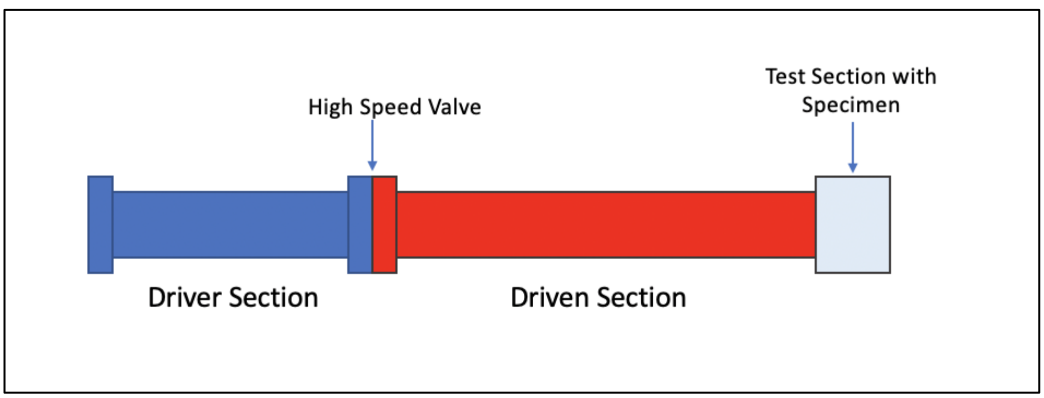

Figure 6. Shock Tube Schematic

The experiment was conducted by adding gas to the driver side until the pressure read approximately 400 psi. At this point, the machine was fired which resulted in the high-speed valve actuating and a shock wave traveling at or above the speed of sound towards the sample. When the shock wave from the driver side contacted the driven gas, pressure was released at the valve and an expansion wave reflected back to the driver section. At the same time, a contact surface was created that initiated a shock wave propagation. This shock wave impacted the sample and was carried to the end of the low-pressure section to the closed endwall of the shock tube [13]. Relationships such as deflection versus time, load versus deflection, and backface deformation energy versus time were calculated and used to evaluate the samples' response.

Once the test was performed, Digital Image Correlation was conducted using ProAnalyst DIC software and relationships such as deflection versus time, load versus deflection, backface deformation energy versus time were determined and total energy was calculated. Line tracking was used to obtain XY coordinates for the impacted regions of the samples to determine the samples' behavior over time. The sample image captured by the high-speed camera was calibrated by setting the sample thickness of the front and back surface so the software was able to recognize how big the viewport is. An example of the calibration information can be seen below in Figure 7. 1-D tracking was enabled and set to track the front and back surface simultaneously over time.

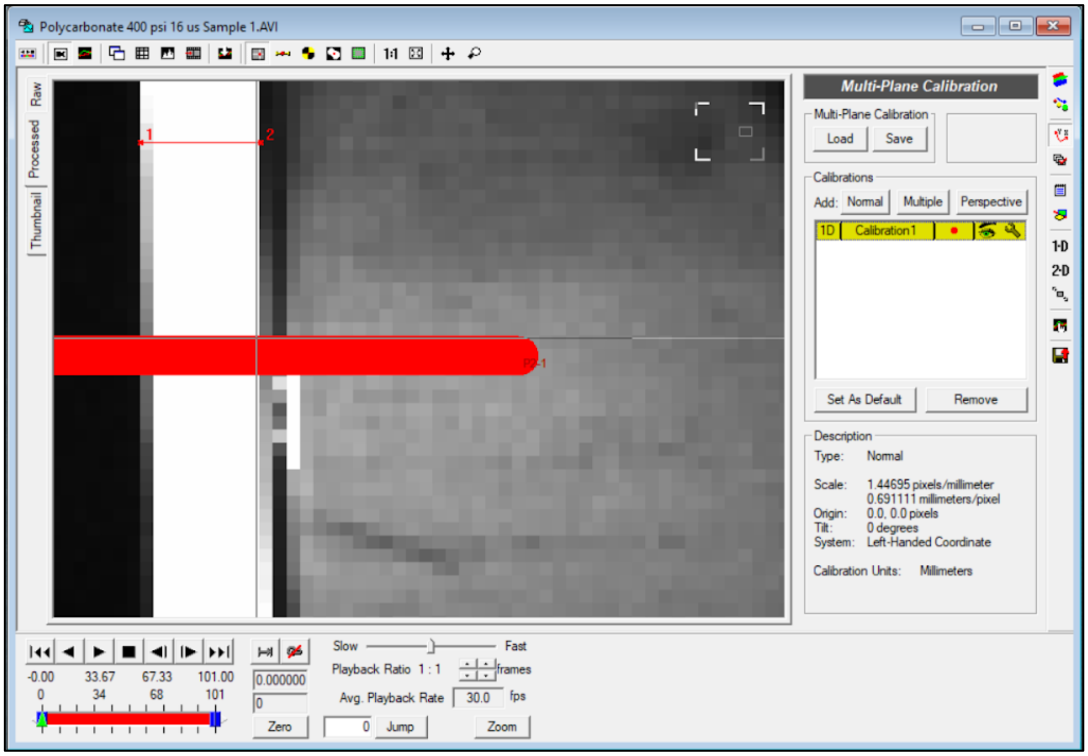

Figure 7. ProAnalyst Calibration Example

Another key aspect to the experimental setup that should be mentioned was the Shimadzu HPV high-speed camera that was placed directly in front of the sample. The camera, as seen in Figure 8, has a resolution of 312 x 260 pixels and was set to capture 63,000 frames per second. Due to the rapid shutter speed, very limited light reaches the camera lens. In order to use the high-speed videos for Digital Image Correlation (DIC), various GSVitec LEDs were placed around the sample to increase image clarity.

Figure 8. Shimadzu High-Speed Camera [14]

Samples with a length of 9.5 inches and a width of 4.2 inches were used in testing. The samples were machined down using a band saw. The samples had a thickness 0.25 inches. The weight of each sample was also recorded before and after UV degradation and used during analysis.

CHAPTER 3: RESULTS AND DISCUSSION

3.1 Visual Effect of UV Exposure

After 15 days of UV radiation, it was observed that there was a significant visual difference in the samples. As seen below in Figure 9, the parts of the sample that were exposed to UV radiation were significantly darker than the untouched parts (such as the circular sections covered by the fixture rings). It should also be noted that the top sample in Figure 9 was partially obscured during UV exposure, leaving the lighter section unconditioned. This sample was left out of dynamic testing data but was useful in understanding the visual damage caused by the UV exposure.

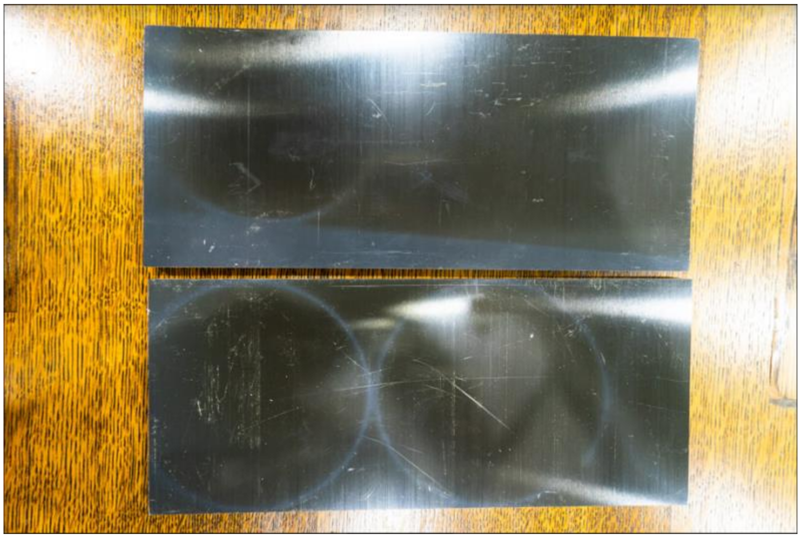

Figure 9. PVC after UV Conditioning

Another visual observation regarding the effects of UV radiation can be seen when comparing the conditioned and unconditioned fragments that were dynamically tested. Figures 10 and 11 depict the unconditioned Polycarbonate and PVC samples after being sent through the shock tube. Figures 12 and 13 depict the conditioned Polycarbonate and PVC samples after being sent through the shock tube. One can observe that the conditioned samples were broken into visibly smaller sections than the unconditioned samples. This gives an initial indication that the UV radiation negatively affected the strength of both materials by causing embrittlement. It is important to note that most of the breakage of the samples occurred when the samples contacted the back of the shock tube and shattered upon impact. This is not necessarily a direct correlation to a samples' ability to absorb the shock wave.

Figure 10. Unconditioned Polycarbonate Samples After Shock Tube Test

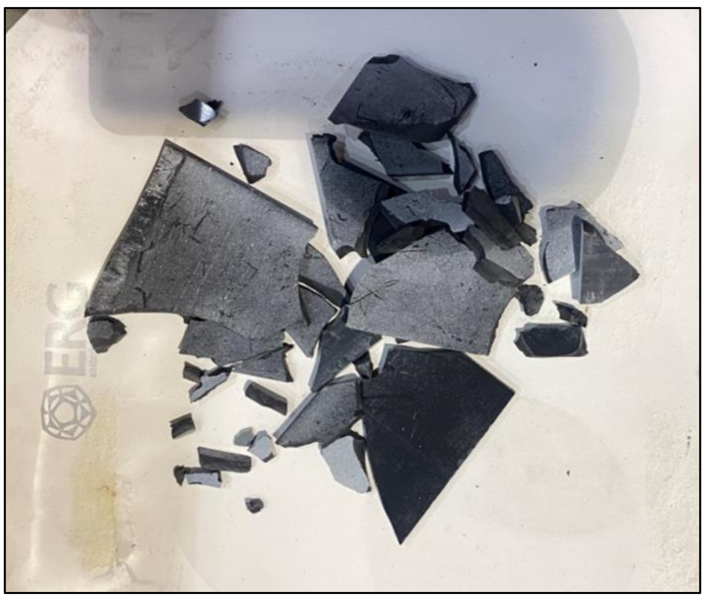

Figure 11. Unconditioned PVC Samples After Shock Tube Test

Figure 12. Conditioned Polycarbonate Samples After Shock Tube Test

Figure 13. Conditioned PVC Samples After Shock Tube Test

3.2 Primary Results

Once each of the control samples and UV-exposed samples were tested in the shock tube, the images captured by the high-speed camera were analyzed by digital image correlation (DIC) in ProAnalyst to determine the behavioral differences between the controlled and UV-exposed polycarbonate and PVC. The first relationship that was analyzed was load versus displacement. Figure 14 below shows this relationship for each of the samples tested in the experiment. To better analyze this data, the average results of the polycarbonate (PC), PVC (PVC), UV exposed polycarbonate (PC_UV) and UV exposed PVC (PVC_UV) were determined by isolating each category on a separate graph as seen in Figure 15. In the case shown, the first tested sample of PVC appears to yield the most average results. Once the average trend was identified for each sample category, the results were summarized against each other as seen in Figure 16. With this summary, it was seen that the unexposed polycarbonate samples were able to resist the most load and more force was required to deform the material. When comparing the difference between polycarbonate and PVC, polycarbonate proved to best withstand the force overall. This is consistent with the knowledge that polycarbonate has an Ultimate Tensile Strength of 65.5 mPa [15], while PVC has an Ultimate Tensile Strength of 52 mPa [16].

It is also important to note the effect that UV degradation had on both materials' load deflection. The data shows that, in the case of polycarbonate, UV exposure significantly decreased the materials' ability to withstand a load by around the same amount throughout the entirety of the load deflection. Additionally, the UV exposed PVC's behavior began to deviate away from the unexposed PVC at about 5 mm. It continued to lose more of its ability to deflect throughout the course of the test. This leads one to believe the PVC degradation resulted in an increase in brittleness.

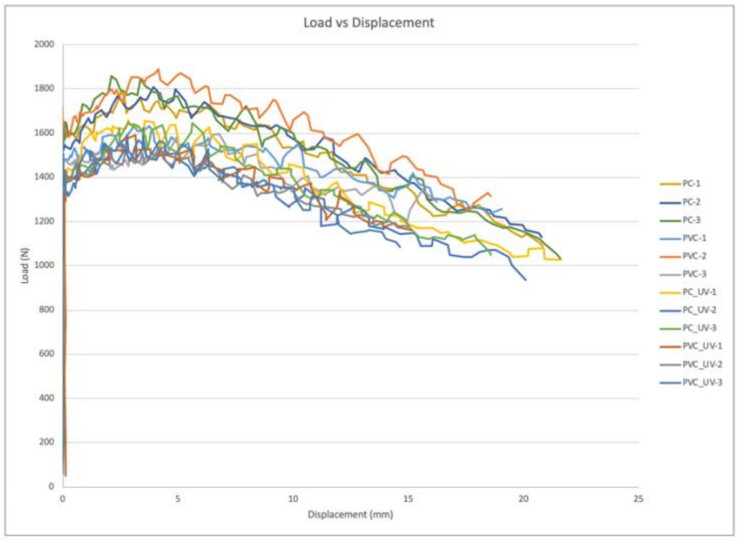

Figure 14. Load vs Displacement, all samples

Figure 15. Load vs Displacement, sample group isolation example

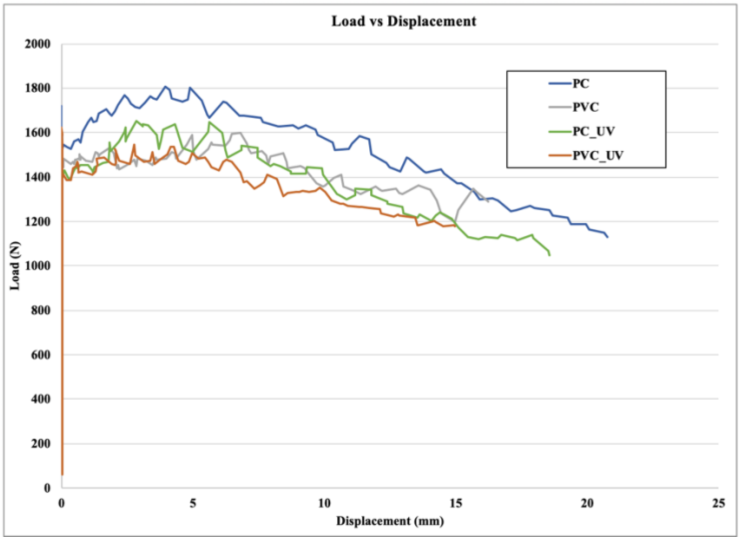

Figure 16. Load vs Displacement, average sample summary

The next way to analyze the characteristic of these materials is to consider the displacement of the back-face sheet center location versus time. As seen in Figure 17 below, the PC was displaced the most over time, followed by PC_UV, PVC, and PVC_UV. This information is consistent with initial assumptions because, since the unexposed polycarbonate was subjected to the most load as discussed previously, it was expected to also experience the most displacement. When considering the effect of UV exposure on these samples' deformation energy over time, it was observed that, even with UV exposure, the polycarbonate samples were able to absorb more energy than either of the PVC samples.

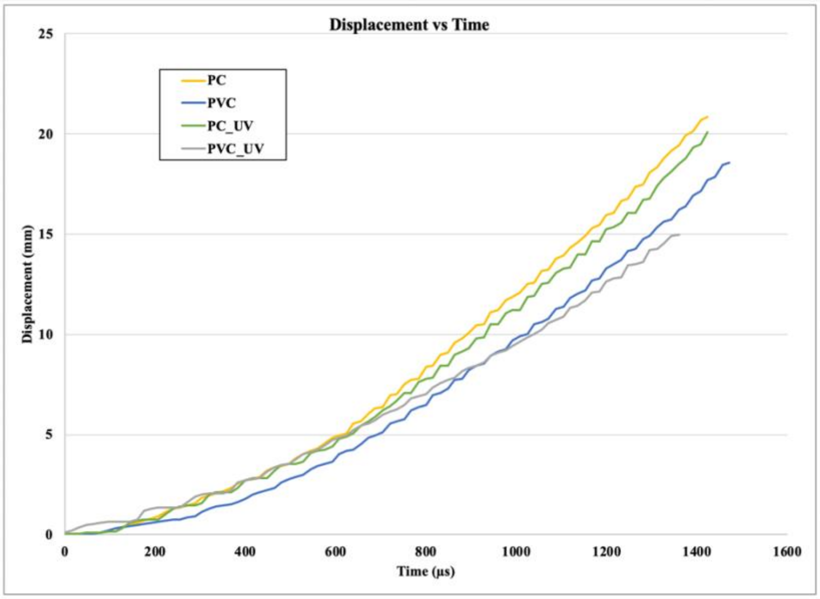

Figure 17. Displacement vs Time, average sample summary

Deformation energy-time curves can be seen below in Figure 18. The slope of the line has a direct relationship with the speed at which energy was able to be absorbed. With this knowledge, one concludes that the unexposed polycarbonate was able to absorb energy the quickest, followed by the exposed polycarbonate, the unexposed PVC, and the exposed PVC. Ability to absorb an impact at a fast rate is extremely important in situations with a high risk of dynamic impact such as in military applications. Thus, this data makes a strong argument for polycarbonate as the preferred material in such applications.

It is also important to note here that there is not much of a decrease in slope between the unexposed and UV exposed PVC samples. This is in contrast to the greater decrease between the unexposed and UV exposed PC. Although PVC is able to absorb less energy overall, its ability to maintain material properties despite UV exposure should be considered.

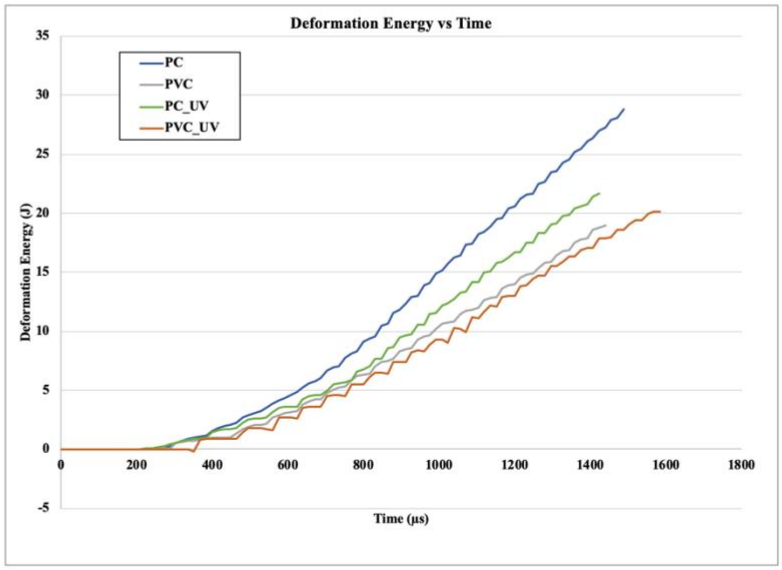

Figure 18. Deformation Energy vs Time, average sample summary

One of the most critical comparisons between these materials was the deformation energy versus displacement comparison shown below in Figure 19. This graph displays which material was able to absorb more energy at any given displacement. It can be seen that the unexposed polycarbonate was able to absorb the most energy throughout the test, followed by the exposed polycarbonate, the unexposed PVC, and the exposed PVC. This is crucial information for engineers because materials chosen for applications with a risk of high-impact need to be able to maintain their strength and ability to resist deformation through the entirety of the shock.

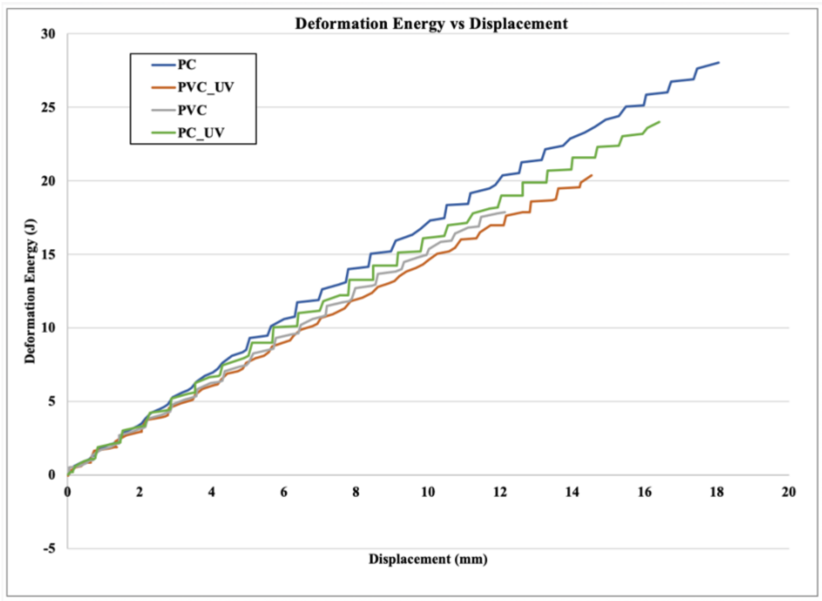

Figure 19. Deformation Energy vs Displacement, average sample summary

The total deflection of each sample was calculated and is displayed graphically in Figure 20 below. The unexposed polycarbonate (PC) had the highest end deflection of 21.01 mm. Compared to the PC, the percent reduction in deformation for PC_UV, PVC, and PVC_UV was 4.7%, 14.8%, and 29.3%, respectively. Based on this observation, there was a large decrease in the total deflection between the exposed and unexposed PVC. With this knowledge, it was concluded that the UV exposure made the PVC more brittle due to its loss in capacity to deflect. Brittleness is not desirable in applications where the material would need to protect fragile elements at risk for dynamic impact, such as solar cells on military vehicles.

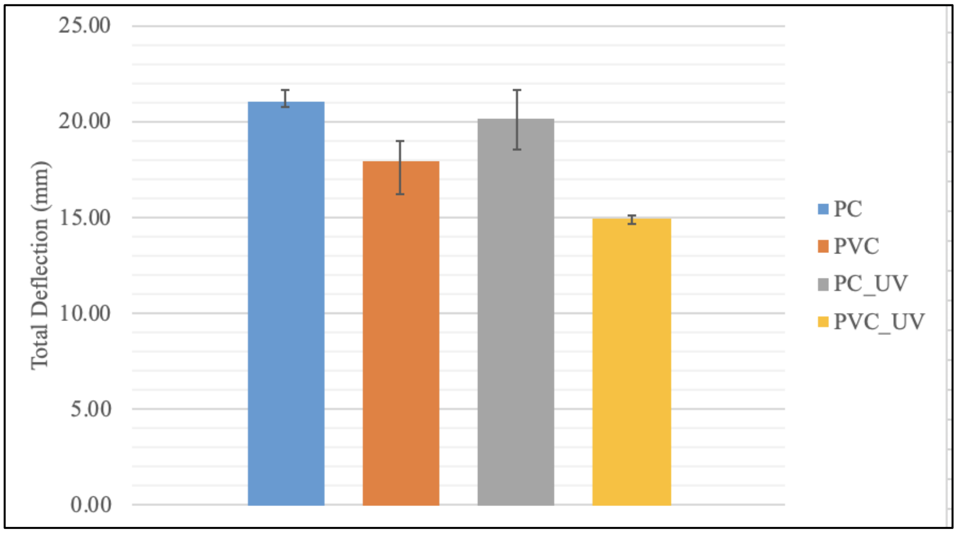

Figure 20. Total Deflection

The following comparisons were based on the lowest displacement of any of the samples tested, which was 14 mm. The specific energy and acceleration were evaluated at this value of displacement.

The specific energy of each material can be seen in Figure 21 below, with PVC_UV having the lowest specific energy of 0.089 kJ/kg. The percent increase in specific energy of PVC, PC_UV, and PC was 12.47%, 29.22%, and 45.21%, respectively. Assuming that all materials have a nearly equivalent mass, the specific energy is an excellent way to analyze which material is expected to absorb the most energy. This data leads one to conclude that polycarbonate was able to absorb the most energy with and without being exposed to UV radiation. Additionally, one can observe that there was a greater drop in specific energy between the exposed and non-exposed polycarbonate than there was between the exposed and non-exposed PVC. This comparison is a crucial one to make because, although polycarbonate may have stronger force resistive properties overall, the PVC may be better at resisting weathering effects that would certainly be seen in applications where the material would be on the exterior of a vehicle.

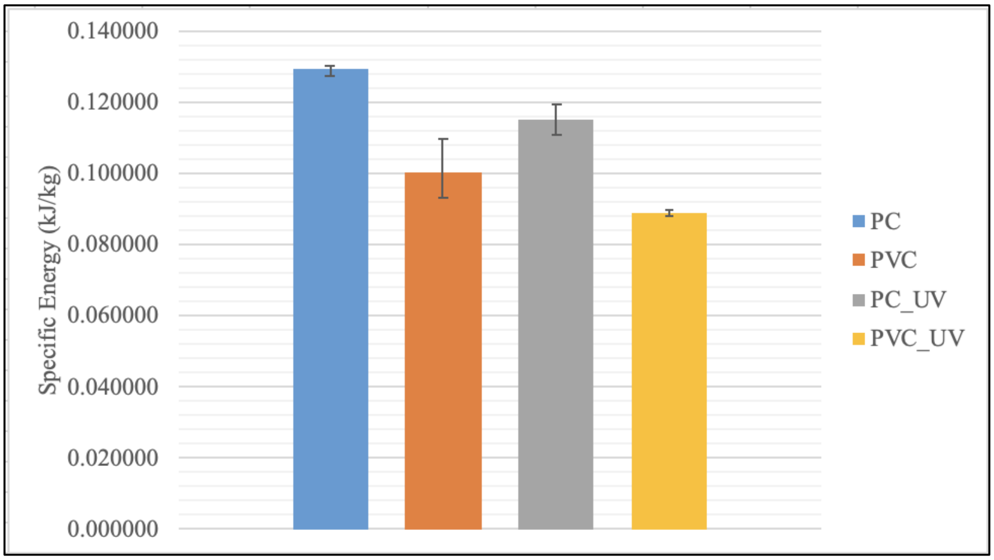

Figure 21. Specific Energy

Finally, each samples' acceleration was graphed against each other as seen in Figure 22. PC had the highest acceleration at 14 mm of 8469 m/s^2. The percent reduction in acceleration as compared to the PC was 2.13%, 21.43%, and 53.46% for PC_UV, PVC, and PVC_UV, respectively. When considering that

F = ma *Equation 16.*

where mass is assumed to be nearly equivalent across all samples, the amount of force hitting the material is directly related to the amount of acceleration. Since the unexposed polycarbonate had the most acceleration, it would impact another structure with the most force. Although this is not desirable, the polycarbonate would still provide the best protection overall because it was able to absorb the most energy.

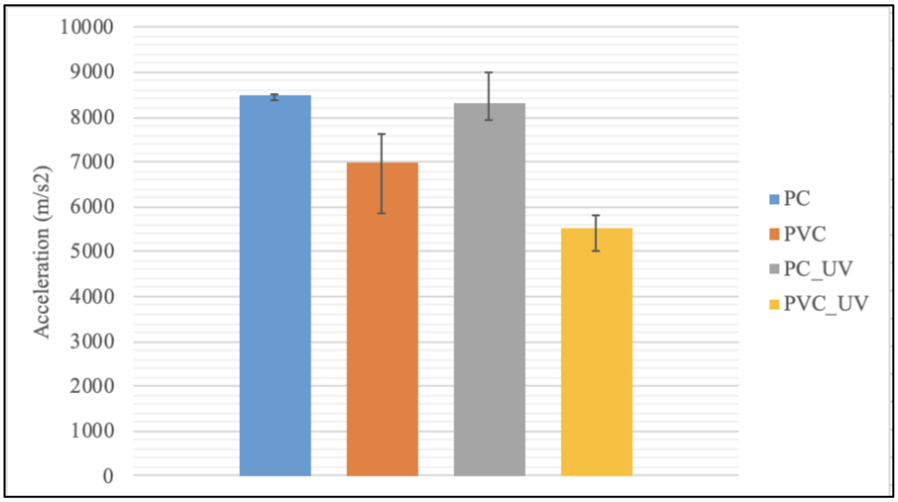

Figure 22. Acceleration

CHAPTER 4: CONCLUSION

After comparing the material properties of polycarbonate and polyvinyl chloride as well as comparing how both materials react to UV radiation, one concludes that polycarbonate is the ideal material for use as the protective material on the exterior of military vehicles. Even after experiencing the weathering effects of UV radiation, the polycarbonate samples were still able to uphold their ability to absorb a shock wave better than the PVC samples. The polycarbonate samples were able to absorb the shock quickly and effectively, which are both crucial requirements for materials used on military vehicles that are at risk for sizeable dynamic impact. Additionally, the weathering affects which would inevitably occur as the material is used on exterior parts of a vehicle did not drastically deplete the polycarbonate's ability to absorb shock and resist deformation.

This study successfully identified an ideal candidate for use as the protective covering of solar cells on military vehicles. Future work involves studying how polycarbonate dynamically behaves after being exposed to other types of weathering, such as water erosion or condensation. Additionally, the samples tested in this research should also be tested using other methods such as the Split Hokinson Pressure Bar, direct impact, and computational simulations. Continued exploration of this topic will allow for the safest, most cost-effective, and most environmentally-conscious solutions for military equipment.

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