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Comparative Analysis and Dynamic Response of Garolites Under Temperature Spectrum Using Low Velocity Impact Test

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COMPARATIVE ANALYSIS AND DYNAMIC RESPONSE OF GAROLITES UNDER TEMPERATURE SPECTRUM USING LOW VELOCITY IMPACT TEST

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 McDonnel Barksdale Honors College.

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DEDICATION:

I would like to express my sincere gratitude to my Mom, Renukadevi Chaudhary and my Dad, Basudev Chaudhary for their immense love and support in every steps of my life. To my big brother, Nagendra Chaudhary, big sister, Sabita Chaudhary, and small brother Dhirendra Chaudhary for their undying love and inspiration. To my Research team and my colleagues who always inspire me and support my work with their innovative ideas and enthusiasm. To all my teachers and advisors who has taught me very well, whose shared knowledge I use every day in my life and has helped me be a better person.

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ABSTRACT

BIRENDRA CHAUDHARY: Comparative Analysis and Dynamic Response of Garolites Under Temperature Spectrum Using Low Velocity Impact Test

The purpose of this study was to examine the dynamic response of three different grades of garolites under temperature spectrum. High Temperature G-11 Sheet (HTG), Impact Resistance Garolite E-glass (HIG) and Economical Garolite (EG) were tested using an Instron Dynatup 8250 impact tester. Three specimens were used for all three composites and were tested at 6 different temperatures, -10ºC, 25ºC, 50ºC, 100ºC, 150ºC and 200ºC using the Low Velocity Impact Machine with 20 Kip punch shear load cell. The results showed that HIG had the highest resistance to punch shear impact. It resisted the highest amount of impact followed by HTG and EG at every temperature tested. The total energy absorbed by HIG was roughly 12 times EG and roughly thrice as much as HTG. The damage propagation energy of HIG was roughly 14 and 3 times than of EG and HTG. Over the temperature spectrum, it was observed that the energy absorption of HIG until peak load was around 11 times and 4 times the energy absorption of EG and HTG respectively. The max impact load for HIG was respectively around 5 times and twice as EG and HTG respectively. Similarly, the max impact absorbed by each Garolite decreased with the increase in temperature. Also, the failure zone decreased with the increase in temperature.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

EG - Economical Garolite

HIG - High Impact Garolite

HIG - High Temperature Garolite

LVI - Low Velocity Impact

CFRP - Carbon Fibre Reinforced Epoxy Matrix

ERDC - Engineer Research and Development Center

SWR - Strength to Weight Ratio

INTRODUCTION

Purpose

The main purpose of this study was to examine the dynamic response of three different grades of garolites under temperature spectrum. High Temperature G-11 Sheet (HTG), Impact Resistance Garolite E-glass (HIG) and Economical Garolite (EG) were tested using an Instron Dynatup 8250 impact tester. Three specimens of each garolites were tested at six different temperatures to get a general idea of the how the materialistic properties change for these garolites when subjected to different temperatures. -10ºC, 25ºC, 50ºC, 100ºC, 150ºC and 200ºC were the temperatures, the specimens were subjected to before testing.

Garolites exhibit some of the most phenomenal properties among the composite materials. Their High Strength to Weight Ratio (SWR), heat resistivity, electrical insulating properties with high chemical resistivity gives them an edge over other composite materials is certainly an intriguing subject to perform research on. This research also inspired three independent researches on garolites which are being carried out at the University of Mississippi.

Dynamic Testing

Dynamic testing is the examination of the physical response from the system. In an experimental research, it is performed to determine the dynamic response of a material to fully understand its dynamic properties. Different kind of dynamic testing can be performed using different dynamic testing equipment. For this research, low velocity impact responses were captured using the Low Velocity Impact Machine. Also known as Drop Weight Impact Testing Machine, the samples are sandwiched in between the clamping fixture to make sure the materials do not move during the testing. Certain clamping force is applied to clamp the samples. The testing can be performed in two different modes: pneumatic mode and gravitational mode. Pneumatic mode ensures the load cell used to moves to the same position as before for successive testing, whereas for gravitational mode, after each test, the load cell has to be moved manually for next testing. The Low Velocity Machine is also equipped with pneumatic rebound brake system to ensure the impact does not occur twice to mitigate any possible damage that could be caused due to series of impacts. Figure 1 shows the Instron Dynatup 8250, Low Velocity Impact Machine, located at the Impact and Dynamics Lab at the University of Mississippi.

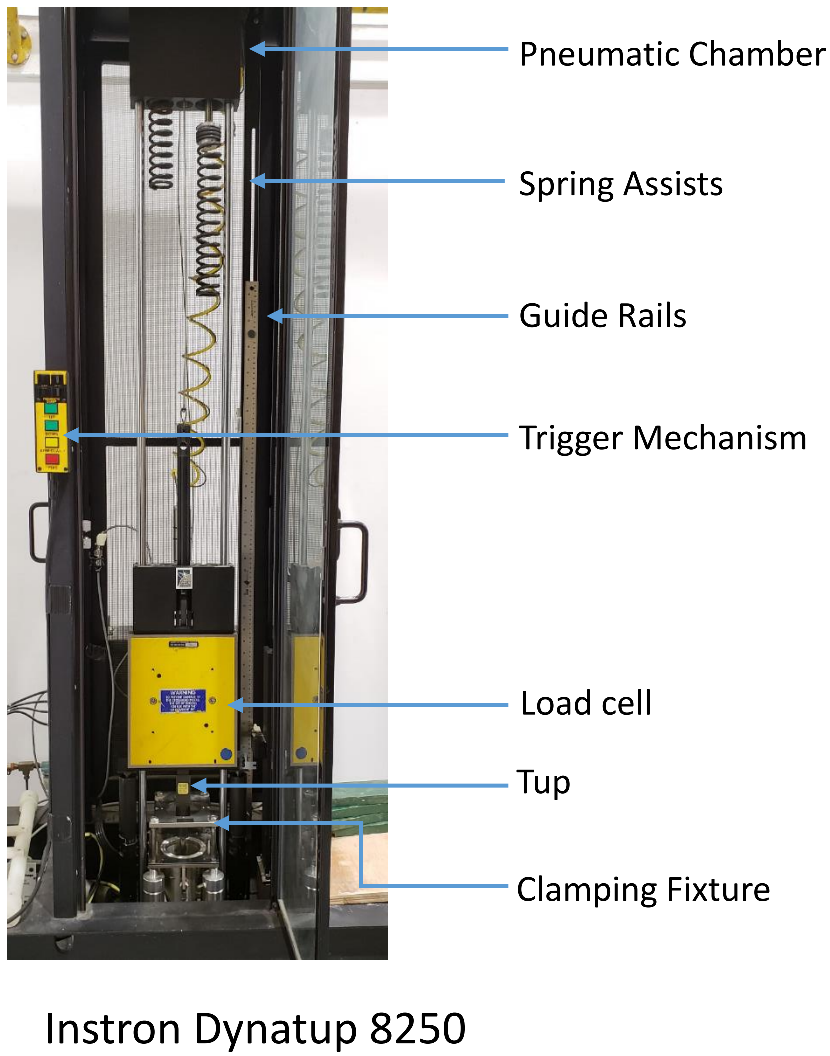

Fig. 1 Low Velocity Impact Machine

Background research

Composite materials provide great benefits because of their high strength-to-weight ratio, compressive strength, corrosion resistance, fatigue resistance, and non-magnetic properties [1]. However, they are vulnerable to damage from low-velocity impact (LVI). Impact may cause any combination of damage modes including fiber crushing, delamination, through thickness shear fracture, and perforation [1]. When composite materials were subjected to mechanical loading and exposed to severe environmental conditions, the natural fiber reinforced composites seemed reasonably strong and had the potential to be used as a material for strong components such as automotive, building materials, shipping etc., although, they had some limitations when compared to reinforced glass such as high moisture absorption and lower strength [2,3].

Garolite is a woven Fiberglass-epoxy laminate material. It is created by stacking multiple layers of glass cloth, soaking in epoxy resin, and compressing the resulting material under heat and pressure until the epoxy cures. Because of the fact that both Micarta and carbon fiber laminates are resin-based laminates, they are very similar to Garolite except for the base material which is glass cloth [4]. As this material has dimensional stability, high strength over temperature combined with very negligible moisture absorption and high level of electrical insulation and chemical resistance, it is used in several aerospace applications, circuit boards, machinery equipment etc. [4,5]. Carbon fiber composites can be replaced by garolite due to similar composition and properties at a fraction of its cost.

Recently Fei Zhou et al reported that the strength decreased with increase in temperature of the Carbon Fiber Reinforced Polymer (CFRP) Tendons due to the softening and decomposition of the resin which weakened the bonding effect of fibers [6]. Another study by B.C.Ray on interfaces of glass and carbon fibers reinforced epoxy composites resulted that a significant weakening often appeared at the interface during the hygrothermal ageing [7]. A work by T. Gomez-del Rio on response of carbon fibre reinforced epoxy matrix (CFRP) laminates at LVI on low temperature suggested that the damage induced in those laminates increased with impact energy. It also stated that cooling the laminate before the impact had an effect on damage similar to that of increasing the impact energy [8].

Many investigators have concluded that the fiber reinforced composites are effective members for concrete members. However, the challenge still exists in the increasing application of those composites such as fully understanding material properties of fiber composites at higher temperatures [9,10]. Very few studies have been done regarding the high temperature effect on the mechanical properties of the fiber composites which is indeed needed. So, to present a better understanding the dynamic response of the fiber reinforced composites, this research used three different grades of Garolite subjected to LVI testing for further study.

In this study, an LVI machine was used to impact specimens and create a punch shear loading scenario. This method is often used in order to focus on the unique impact damage behavior in a material [11]. An LVI test is very different from high impact velocity test or quasi-static test. For LVI, the contact duration is sufficiently long enough for the entire structure to respond to the impact and energy is absorbed elastically and/or eventually in damage creation whereas for high velocity, the impact event is short and the structure may have no time to respond in flexural or shear modes [12]. The quasi static test is performed at a very slow rate such that the internal equilibrium of the specimen is maintained.

Hypothesis

The main purpose of this study was to examine the dynamic response of three different grades of garolites under temperature spectrum. High Temperature G-11 Sheet (HTG), Impact Resistance Garolite E-glass (HIG) and Economical Garolite (EG) were tested using an Instron Dynatup 8250 impact tester. Three specimens were used for all three composites and were tested at 6 different temperatures, -10ºC, 25ºC, 50ºC, 100ºC, 150ºC and 200ºC using the Low Velocity

Impact Machine with 20 Kip punch shear load cell. In this experiment, it is expected that the maximum impact energy absorbed by the garolite composites will decrease over the elevated temperatures. It is also expected that the Impact Resistance Garolite would be absorb the maximum amount of energy and show highest deflection during punch shear during to its higher strength.

MATERIALS AND METHODS

Materials

Three different grades of garolites were used for this for this research to examine their dynamic response at different temperatures. Garolite is a common name of Fiberglass-epoxy laminate material and is specified for is specified for its extremely high strength and high dimensional stability over temperature [13]. Commonly known as fiber-based composite, garolite like many composite materials are strong and more rigid than plastic, lighter than metal but cannot be bent or formed like polyethylene, nylon, or other common plastic materials due to tis rigid nature [14]. Due to this, it is very difficult to cut or machine and requires special equipment to do so. Garolites in general are very strong materials with high Strength to Weight Ratio (SWR). Their coefficient of thermal expansion is minimal and absorb very less moisture / water. Resistivity against chemicals and flame retardant properties make it very useful in hazardous environment and its use in circuit boards is prominent due to its insulating properties. Garolites are often used as machine guards, fire arm grips, handles, machine compartments, pip saddles, mechanical parts and several aerospace applications.

G-9 Fiberglass Melamine Laminate Sheet, G-10 Fiberglass Epoxy Laminate Sheet and G-11 Fiberglass Epoxy Laminate Sheet are the most common type of garolite used. For the purpose of this research, the Impact-Resistant Garolite E-Glass (also called High Impact Garolite, HIG), Economical Garolite CE Sheets and High-Temperature Garolite G-11 Sheets were used. A combination of high impact strength and extreme hardness makes the Impact-Resistant Garolite E-glass very difficult to penetrate [15]. Often used for machine guards, it is constructed of a phenolic resin with fiberglass fabric reinforcement. As per McMaster Carr, the standard hardness for HIG is Rockwell M110 which is categorized as Extra Hard. The tensile strength and Impact Strength of

HIG lies around 39,000-63,000 psi (categorized as excellent) and 15 ft.-lbs./in. (also categorized as excellent) respectively. The HIG appears to be brown in color [16]. HIG is a woven material which makes it an excellent impact absorber.

Economical Garolite CE Sheets (EG) are often fabricated into parts where high strength is not required [16]. Sometimes also called canvas-grade industrial laminate, phenolic, and Bakelite, these CE sheets are made of a phenolic resin with cotton fabric reinforcement, which makes it easy to machine into mechanical parts, such as pulleys, gears, bushings, and washers. As per McMaster Carr, the standard hardness for HIG is Rockwell M110 which is categorized as Extra Hard. The tensile strength and Impact Strength of HIG lies around 6,000-10,000 psi (categorized as good) and 1.4-1.7 ft.-lbs./in. (categorized as poor) respectively [16]. The HIG appears to be light brown to greenish in color is made up of fabric ply layer.

High-Temperature Garolite G-11 Sheets (HTG) offers higher strength and better heat resistance than Garolite G-10/FR4 sheets [17]. These sheets are suitable for continuous use in elevated temperatures but is slightly weaker than their G-10 counter parts. Sometimes also called epoxy-grade industrial laminate and phenolic, these sheets are made of an epoxy resin with fiberglass fabric reinforcement and retain at least 50% of their structural strength at temperatures above 300° F making it highly useful for high temperature applications. As per McMaster Carr, the standard hardness for HIG is Rockwell M110 which is categorized as Extra Hard. The tensile strength and Impact Strength of HIG lies around 37,000-58,600 psi (categorized as excellent) and 7-15.3 ft.-lbs./in. (also categorized as excellent) respectively [17]. The HTG appears to be green in color and is made up of fabric ply layer.

Methods

All three Garolites were obtained from a private supplier of raw materials, tools and equipment, McMaster-Carr. They were ordered as a 30 cm Wide x 30 cm Long x 0.625 cm thick. The materials were then sized to fit into the Low Impact Velocity Machine and were milled using the Saw machine at the Machine Shop at The University of Mississippi. The samples dimensions of approximately 10 cm x 10 cm were prepared for the testing. Figure 1 shows the sample specimens for each garolite kept at room temperature (25^{o}C).

To get a proper understanding of the mechanical properties the garolites at varying temperature, these samples were heated up-to 200^{o}C and tested in the LVI machine. Similarly, to test the materials at -10^{o}C, an industrial freezer at the Center of Manufacturing Excellence, was used. The freezer was kept at a constant temperature of -25^{o}C. An ice bath was prepared to transport the samples from the freezer to the LVI machine to keep the samples from gaining too much ambient heat from the surrounding. Samples were sealed inside a plastic bag while in the ice bath.

Fig 2. Sample Specimens for High Temperature G-11 (left), Economical Garolite (middle) and Impact Resistance Garolite (right)

Since the temperature of the heated samples and the cooled sample were different than the ambient temperature, heat loss (for the samples at higher temperature) and heat gain (for the samples at lower temperature) would occur. Due to this phenomenon, the samples at higher temperature were heated to higher temperature than required temperature to counteract the heat loss. For this, an estimation of 40 seconds to place the samples under the clamping fixture and test was used.

It was assumed that the internal resistance of the body (conduction) was negligible in comparison with the external resistance (convection). The Lumped Heat Capacity Formulae was used to calculate the temperature the samples would need to be inside the oven before testing. Also, the time the samples would require to maintain a uniform temperature both inside and outside was calculated [18]. An infrared thermometer was used to measure the temperature of the samples.

EXPERIMENTAL SETUP

Low Velocity Impact Test

All the impact tests for 3 different grades of garolites at 6 different temperatures were conducted on an Instron Dynatup 8250, the LVI Machine with the pneumatic rebound brake system at the Structure and Dynamics Lab at the University of Mississippi. A 20 Kips load cell was used for puncturing through the samples with hemispherical tip of roughly 12.7 mm. The Pneumatic assist force was kept at 80 Psi throughout the entire testing for consistency. Specimens were impacted with the load mass of 35 Kg with the impact velocity being roughly 5.7 m/s. The and impact energy due to the impact roughly clustered around 565 J – 570 J. Similarly, the clamping force, used to clamp the samples within the clamping fixture to avoid any movement during the shear puncture, was kept at 80 Psi. Same clamping force was used to hold the samples throughout the experimentation for consistency.

Data Acquisition

A personal computer-based data acquisition system, supplied by Dynatup, was triggered by a photo diode velocity detector just prior to impacting the specimen and was used to collect data from the load cell tup. The rebound brake was also triggered by the velocity detector and engaged after the initial impact to prevent multiple impacts on the test specimens [19]. The specimen was fixed in between the steel clamp. It was indented with the indenter tup of radius 12.7 mm. During testing, a linear variable displacement transducer mounted under the specimen recorded the displacement of the center of the indenter. For each test, the load versus indenter displacement data was collected via a digital data acquisition system. The free-falling impactor was allowed to fall along two smooth guided columns upon release and the total displacement of impactor and top skin deflection were recorded as a function of time with a data acquisition system with the sampling rate of 30,000 Hz. [20].

Camera and Lighting System

Shimadzu HPV-2 High-Speed Video Camera with a fixed resolution of 312 x 260 pixels and recording speed of 32,000 frames per second was used to capture the impact. The illumination was provided by GS Vitech MultiLED QT system to capture clear images and provide enough lighting during impact due to very low exposure time. Figure 3 shows a clearly focused image of HTG captured by Shimadzu HPV-2, clamped in between the clamping configuration just before the impact and illuminated by GS Vitech MultiLED QT system.

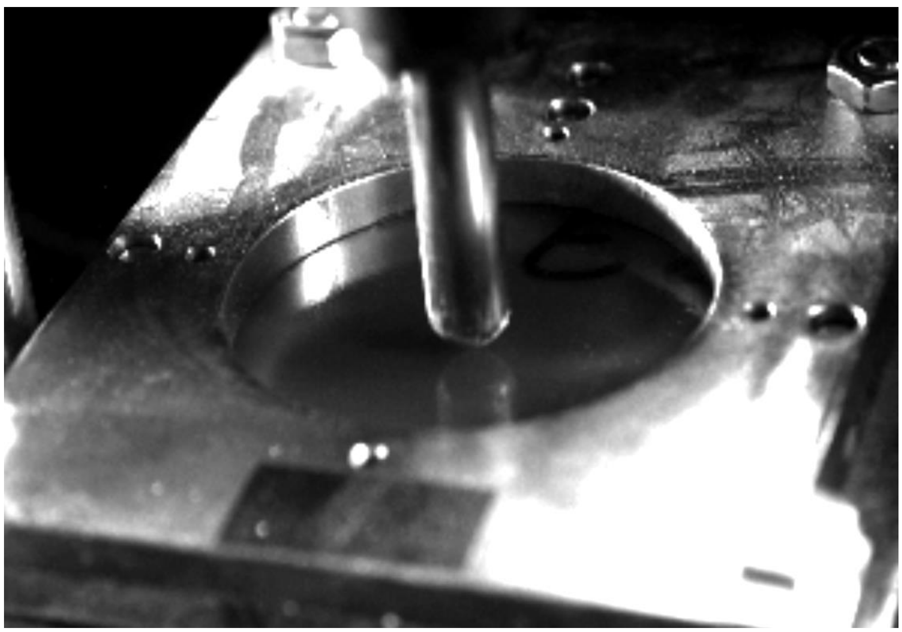

Fig. 3 Imaging of High Temperature Garolite with the Use of Lighting

ASME Standard

The standard used to conduct the testing was (American Society of Testing and Materials) ASTM D3763-10, a standard method for high speed puncture properties of plastics using load and displacement sensors. According to this standard, the impact energy was kept over thrice the required energy to fully puncture the specimen to keep the velocity slowdown within 20% [21].

RESULTS AND DISCUSSION

The impact tests were performed using the LVI machine for three different Garolites, HTG, HIG and EG. Each material was tested at 6 different temperatures and 3 specimens of each garolite were tested at each temperature. Figure 4 shows the different phases of loading and energy propagation thought the impact.

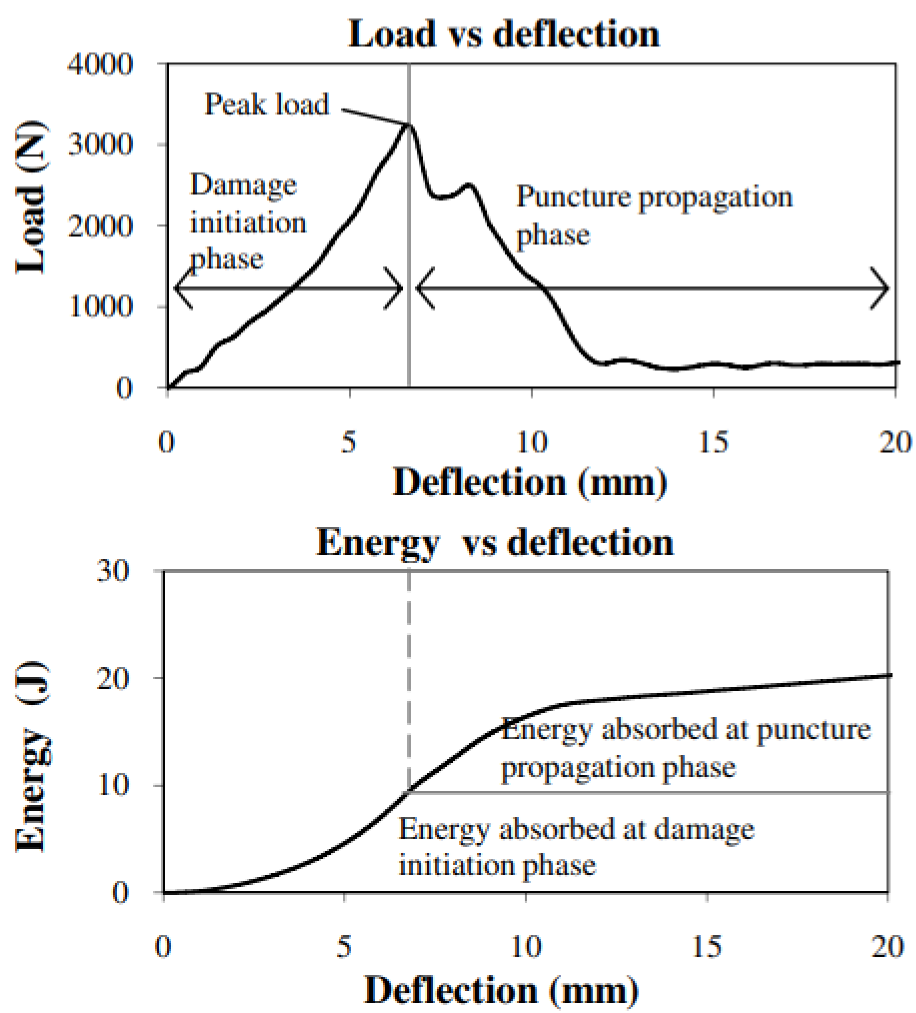

Fig 4 Punch-shear failure phases in puncture deflection frame [22]

As seen in figure 5, damage initiation energy is the first phase which starts the moment the load tup impacts the sample to the point of peak load where the damage initiates with almost uniform deflection with some initial fracture peaks [22]. Similarly, after the point of peak load, the puncture initiates which rapidly reduces the load called the puncture propagation phase whereas the total energy absorbed by the material as soon as the load tup impacts the sample to the complete shear punch through to complete failure induced by the shear punch through is called total energy absorption.

Load vs Deflection Results

In General, the maximum load a specimen can withstand decreased with increase in temperature for all three Garolites with lowest being the load at 200°C for each Garolite which can be seen in Figure 4, Figure 5 and Figure 6 respectively for HTG, EG and HIG. However, the max load increased from -10°C to 25°C (room temperature). This could be because the materials, when manufactured, are aimed to work best at the normal room temperature and as the material goes to high temperature, they degrade causing the loss of impact load resistance. The max load absorbed by the specimens under the different temperature spectrum is listed in Table 1.

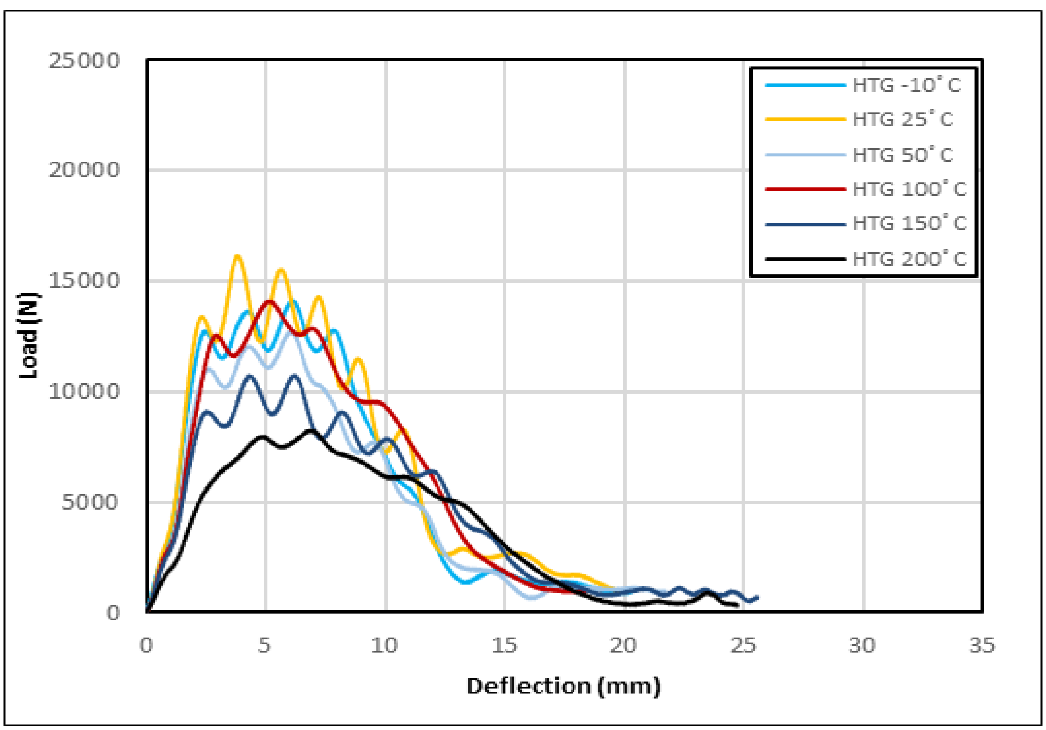

Fig. 4 Load vs Deflection Curve of High Temperature Garolite

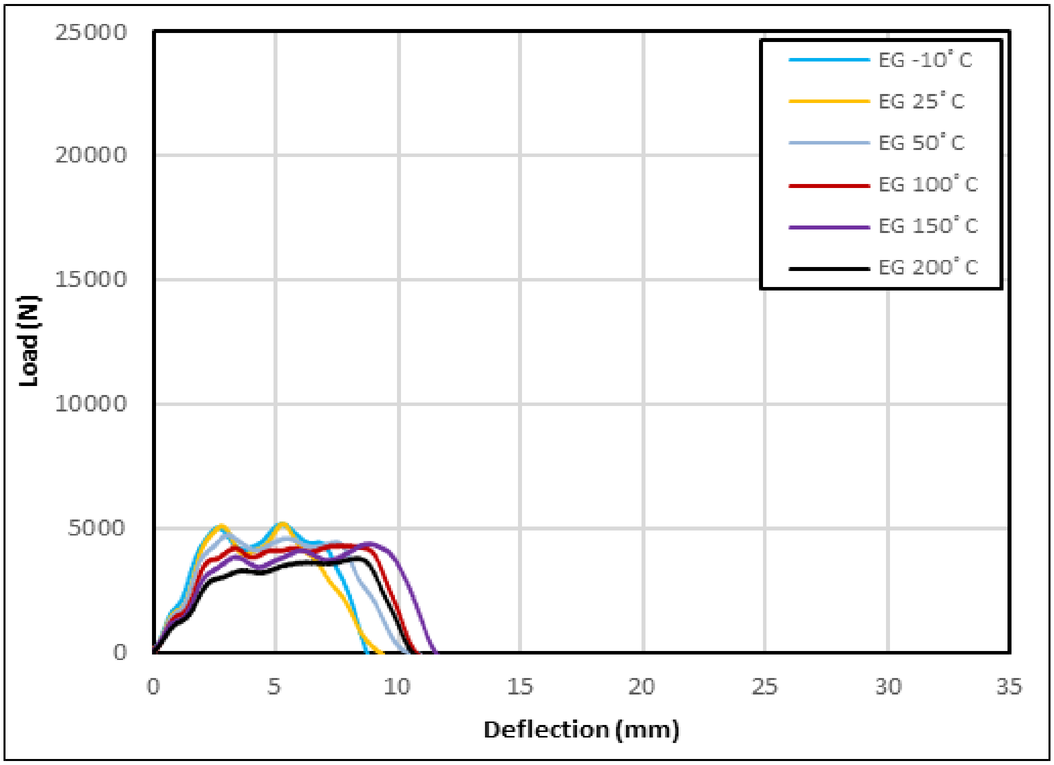

Fig. 5 Load vs Deflection Curve of Economical Garolite

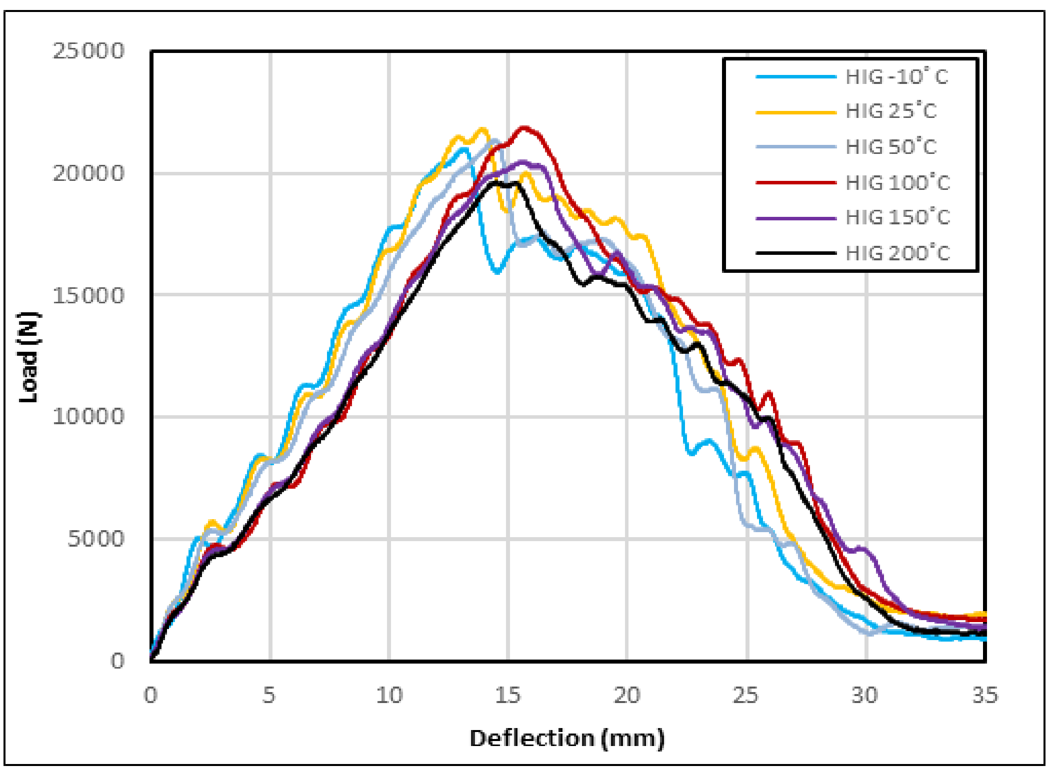

Fig. 6 Load vs Deflection Curve of High Impact Garolite

Max Load Results

The max load withstood by EG and HTG was maximum at room temperature. A downward trajectory can be seen after the room temperature as the temperature increases. This could be due to the material degradation of the resin causing weak bonds and softening at increased temperature. However, a large drop in impact load for HTG from 25^{o}C to 50^{o}C was seen. This could be due to the inconsistency in the samples which is fairly typical among the composites. A fairly consistent max load was seen for HIG up-to 50^{o}C followed by a downward trajectory. The impact load seems to be higher at -10^{o}C than at 25^{o}C but is within the statistical spread and needs more investigation. A column chart to compare the max impact load at each temperature for all the garolites is shown in Figure 7.

Table 1: Max Impact Load in Joules for all three grades of garolite at various temperatures

	-10 ^{o}C	**25 ^{o}C**	**50 ^{o}C**	**100 ^{o}C**	**150 ^{o}C**	**200 ^{o}C**
HTG	12328.07	16299.83	12727.33	13834.27	10572.90	8290.77
HIG	21423.04	21040.40	21682.17	21081.90	20120.50	19694.73
EG	4253.45	5255.23	4798.57	4584.97	3664.63	3377.10

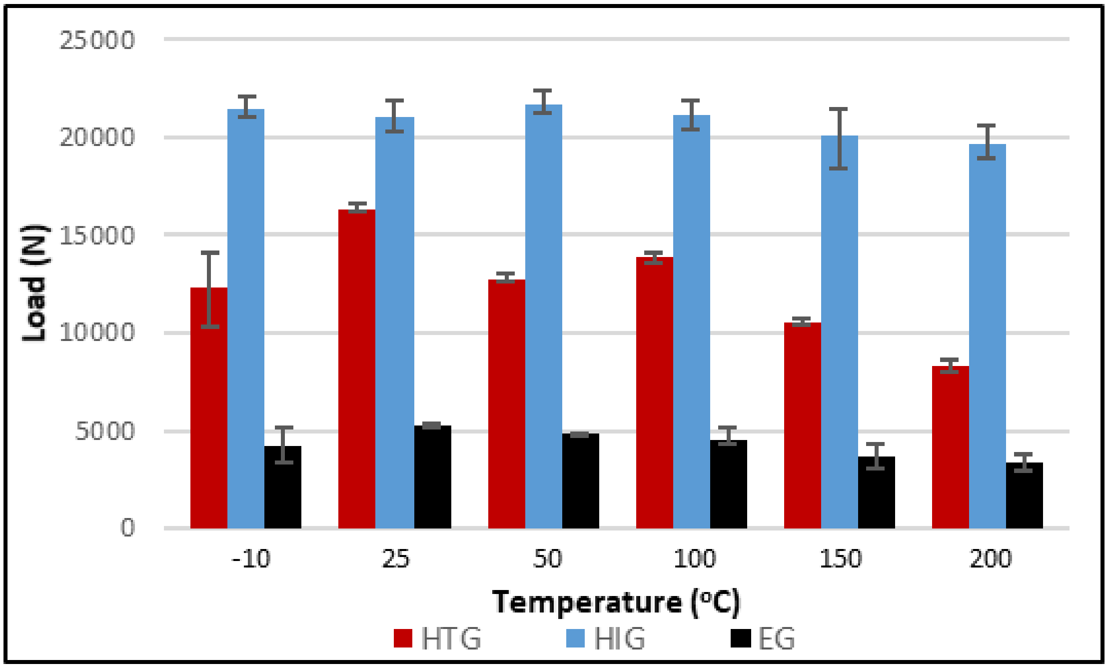

Fig. 7 Max load at different temperature

A side by side comparison of each Garolite for Load vs Deflection at a fixed temperature showed that HIG absorbed the highest amount of impact than the other composites with EG Garolite being the weakest. Similar trend was seen at each temperature tested which confirms that HIG was indeed the strongest among the test samples. HIG is a woven material which has been shown to resist high amounts of impact providing better energy absorption. The load vs deflection curve for different garolites at -10°C, 25°C, 50°C, 100°C, 150°C and 200°C are shown in Figure 8, 9, 10, 11, 12 and 13 respectively.

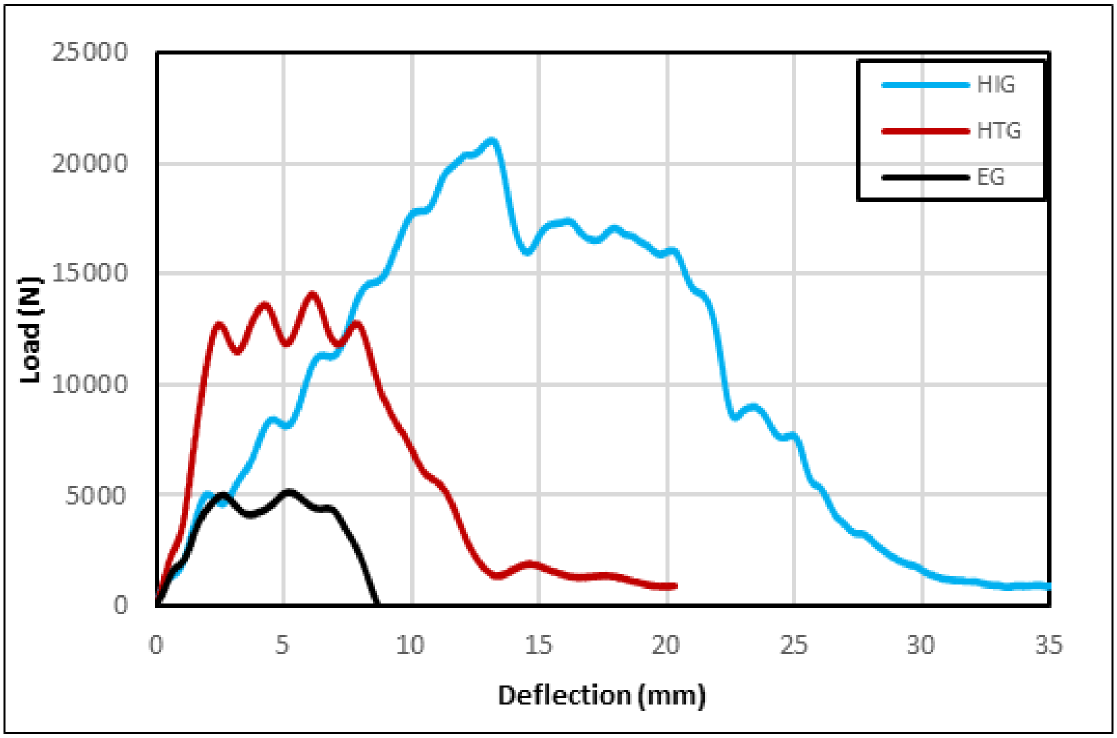

Fig. 8 Side by side load vs deflection comparison of garolites at -10ºC

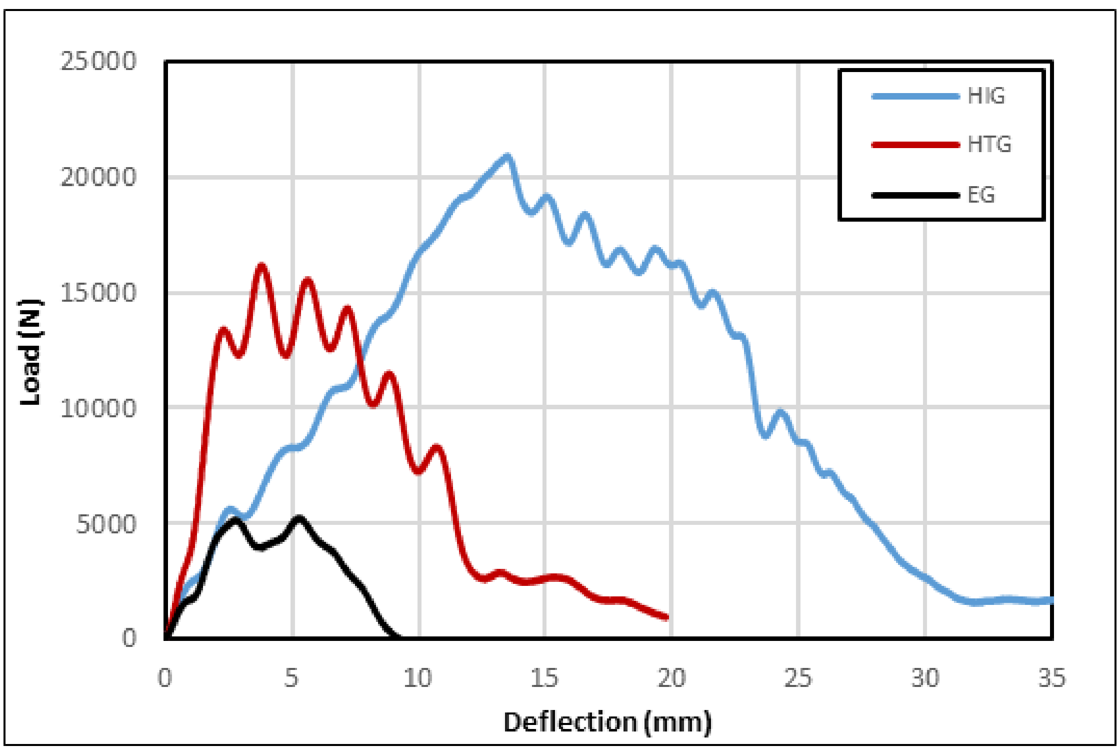

Fig. 9 Side by side load vs deflection comparison of garolites at 25ºC

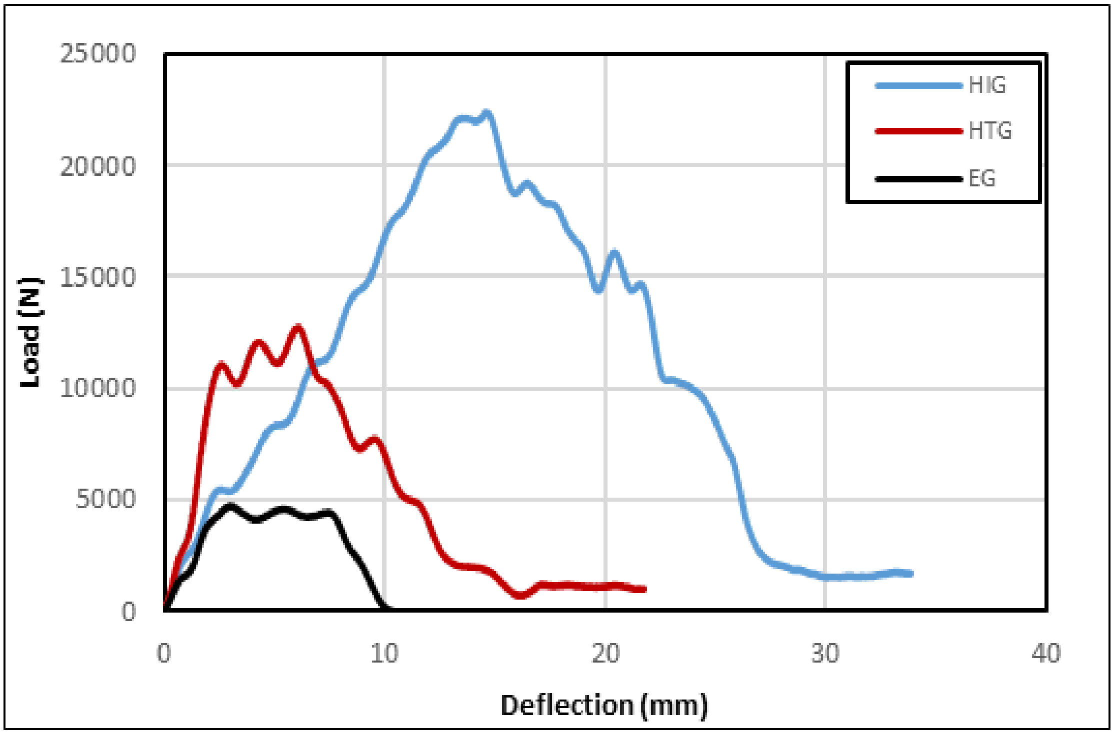

Fig. 10 Side by side load vs deflection comparison of garolites at 50ºC

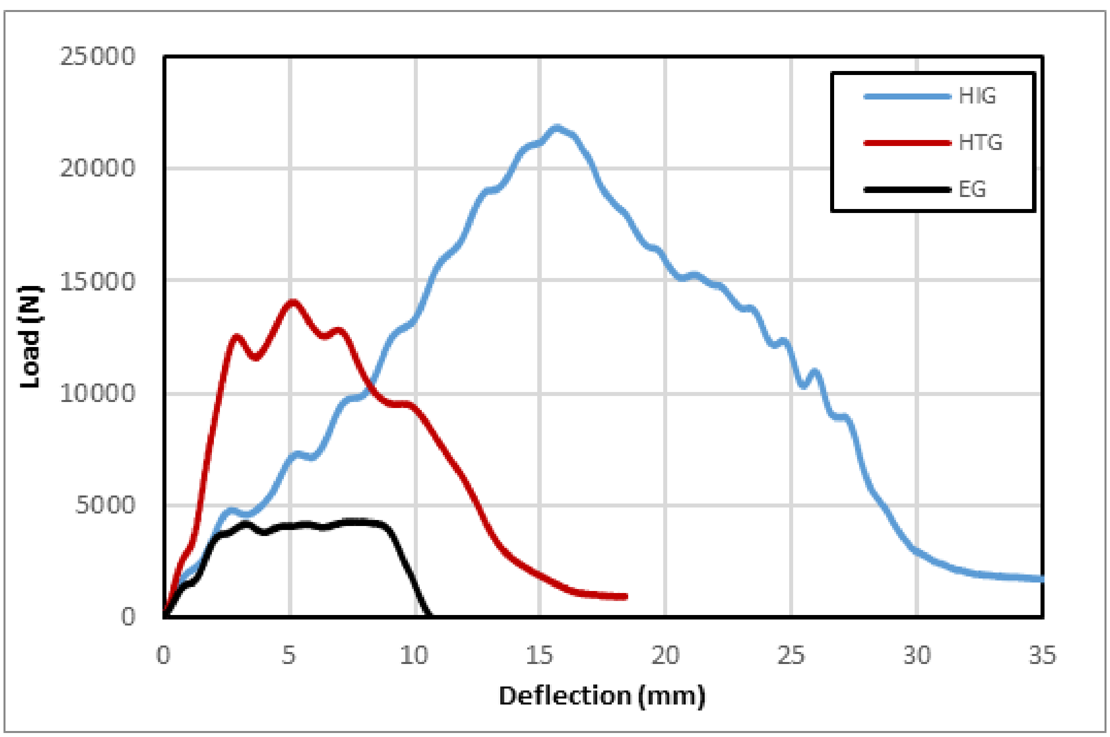

Fig. 11 Side by side load vs deflection comparison of garolites at 100ºC

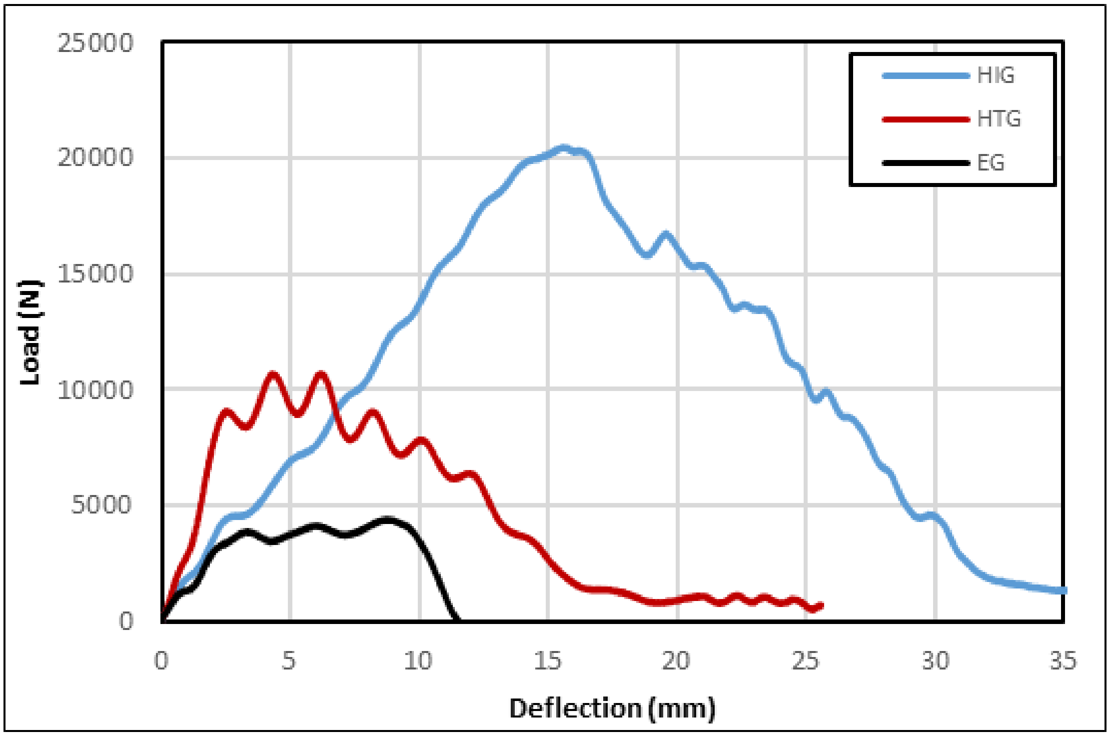

Fig. 12 Side by side load vs deflection comparison of garolites at 150°C

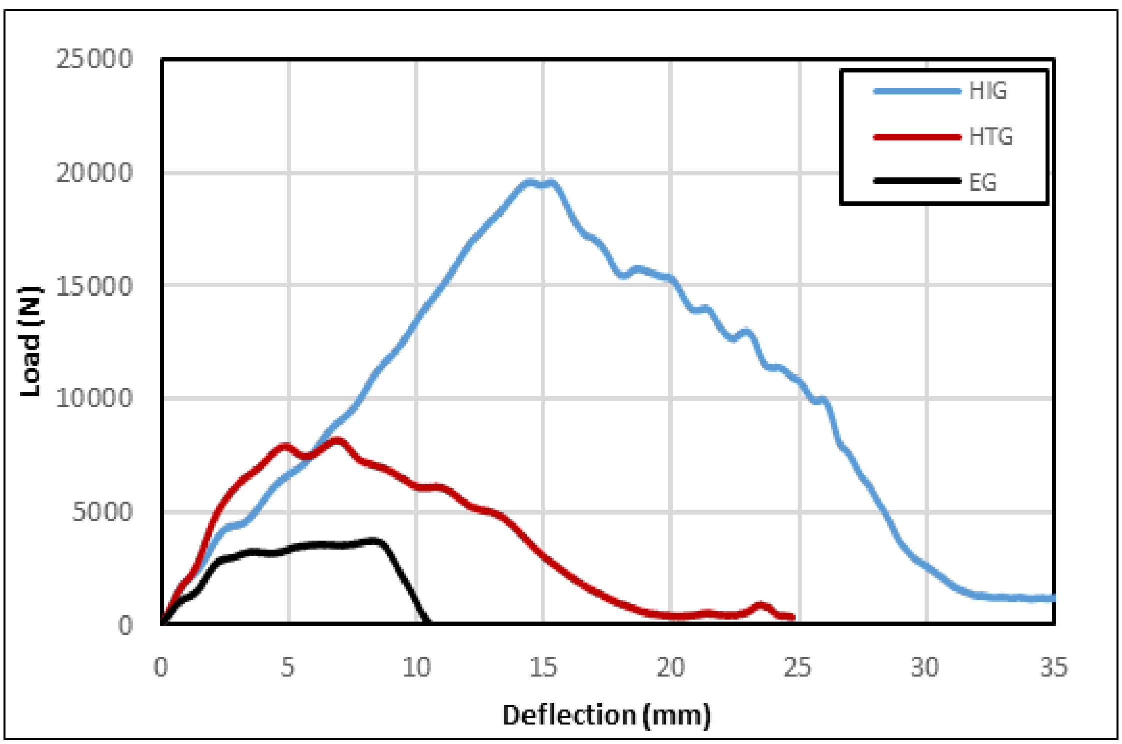

Fig. 13 Side by side load vs deflection comparison of garolites at 200°C

It can be seen that the spread of the load vs deflection graph for all three garolites at all temperatures were significantly different. This is due to the failure pattern of the garolites. Huge deflection was seen on HIG samples before shear punch through making. Due to this failure pattern, it absorbed the most energy and is ductile. Some resistance was seen on HTG samples before punch through, through cracks causing more energy absorption than EG but less than HIG. Also, no visible cracks or deflection was seen on EG samples and the shear punch was seen as soon as the load cell hit the sample due to which it absorbed less energy making it more brittle than HTG and HIG.

Energy to Max load Results

Table 2 shows the energy to max load of all three garolites tested at different temperatures and figure 14 shows the column chart for the energy to max load for all three garolites tested at different temperatures

Table 2: Energy to Max Load in Joules for all three grades of garolite at various temperatures

	-10 °C	**25 °C**	**50 °C**	**100 °C**	**150 °C**	**200 °C**
HTG	42.78	50.04	52.96	41.52	27.17	38.08
HIG	159.68	150.09	160.92	171.67	175.48	147.31
EG	11.07	11.07	14.66	19.36	22.18	11.71

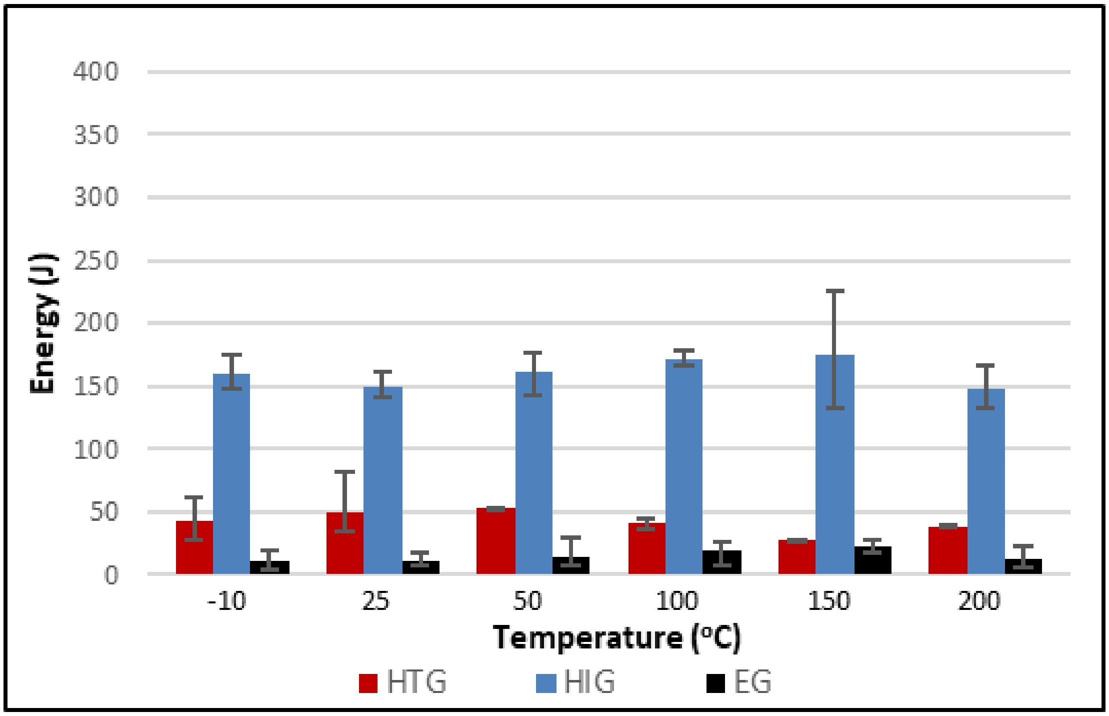

Figure 14. Energy to Max Load

Looking at the Energy to max load chart, it can be seen that there was a general increasing trend for HIG and EG up to 150°C. The reading at -10°C does not follow the trend and hence needs further investigation. The decrease at 200°C could be due to the brittle transition of the material or degradation of the resin. The large error bar for HIG at 150°C could be due to the inconsistencies in the samples and need more testing. Similarly, an upward trend was seen up to 50°C and a downward trend up to 150°C for HTG. This could be due to the fact that HTG's can only work up-to a certain high temperature and may not react well to extreme temperatures above 150°C. The sudden increase at 200°C could be due to the inconsistency in the samples and require further investigation.

Damage Propagation Energy Results

Table 3 and column chart in figure 15 represents the energy absorbed in Joules by the Garolites at different temperature after the point of peak load to complete failure induced by the shear punch through.

Table 3: Damage Propagation Energy in Joules for all three grades of garolite at various temperatures

	-10 °C	25 °C	50 °C	100 °C	150 °C	200 °C
HTG	51.51	90.73	58.64	88.32	85.59	55.67
HIG	188.43	200.55	183.14	193.69	174.17	176.73
EG	12.18	19.76	21.36	15.34	6.43	11.67

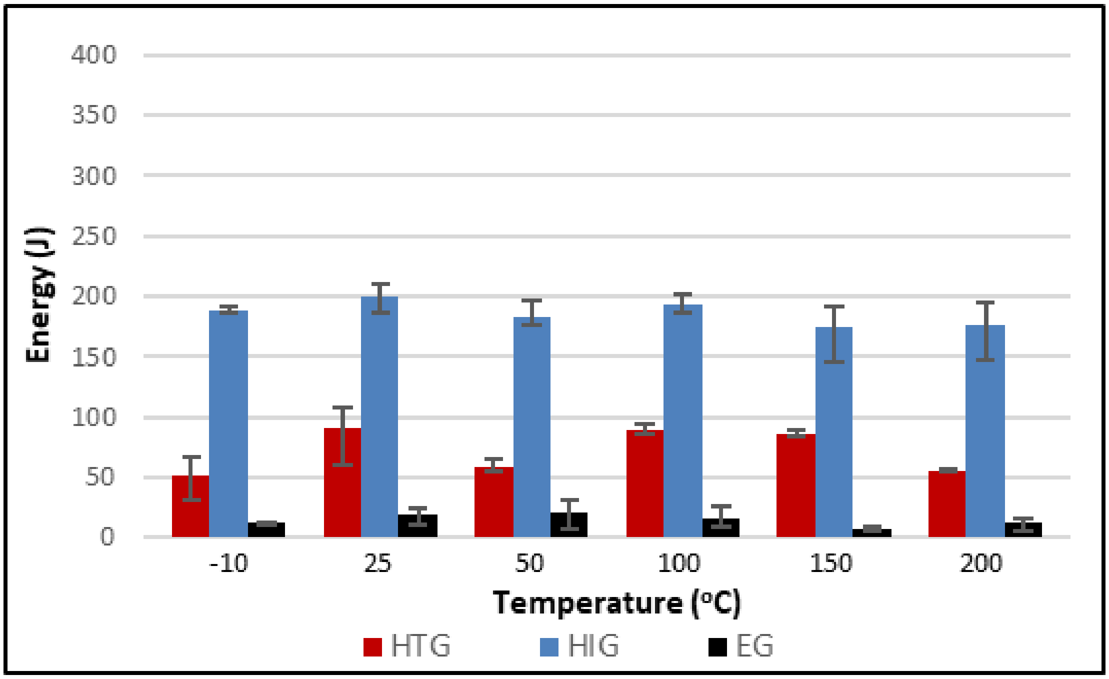

Figure 15. Damage Propagation Energy

It can also be seen that HIG propagates highest amount of energy among all these garolites, even at high temperatures. HIG would provide better impact resistance in high temperature applications. The damage propagation is more dependent on damage mechanism than temperature and hence none of the garolites showed a consistent pattern.

Total Energy Absorption Results

Table 4 and column chart in figure 16 represents the total energy absorption in Joules by the Garolites at different temperature.

Table 4: Total Energy Absorption in Joules for all three grades of garolite at various temperatures

	-10 °C	25 °C	50 °C	100 °C	150 °C	200 °C
HTG	94.31	140.78	111.60	129.84	112.76	93.75
HIG	348.11	350.64	344.06	365.36	349.64	324.04
EG	23.24	30.82	36.03	34.70	28.61	23.39

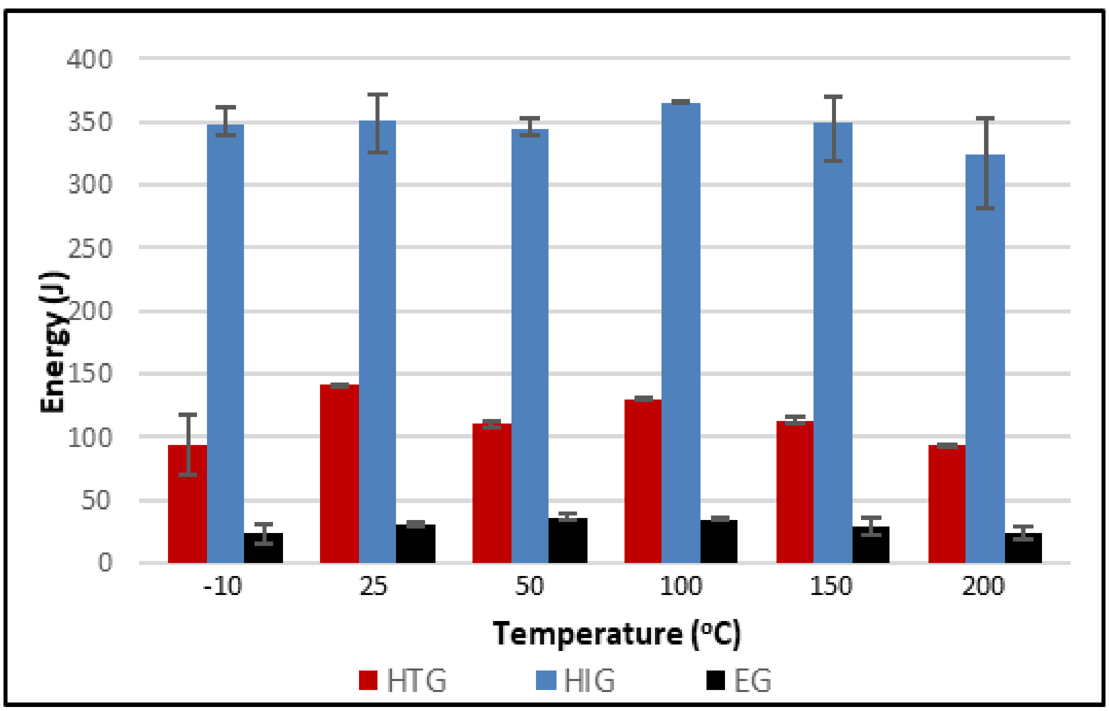

Fig.16 Total Energy Absorption in Joules

It can be seen that HIG absorbed the highest amount of energy while EG absorbed the least. This could be due to the failure pattern of these garolites and the configuration of the layers. HIG is a woven material and deflection was seen before delamination during the test which can be seen in figure 17. This helps in the absorption of huge amount of energy. Similarly, crack propagation was observed during shear puncture for HTG and a punch through for EG which can be seen in Figure 18 and 19 respectively. Due to the shear punch through, EG does not absorb much energy while HTG absorbs some energy during damage propagation through cracks. The total energy absorbed by HIG was fairly consistent throughout all the temperature, with a slightly decreasing trend after 150^{o}C. Similarly, HTG absorbed the highest energy at 25^{o}C and showed a decreasing trend with the increase in temperature except at 50^{o}C which showed a large dip in the values. This could be due to the failure pattern or the inconsistency in the samples. As for EG, the total absorption was fairly consistent and did not change much due to its nature. The total energy it absorbed was comparatively lower than the others and hence the change due to increase in temperature was minimum. However, an increasing trend up-to 50^{o}C, followed by a decreasing trend with the increase in temperature was seen.

Failure Zone Analysis

It can also be observed that the failure zone relatively decreased with the increase in temperature. Further investigation would be required to understand the underlying mechanisms causing the phenomenon. Figure 17 shows the failure zone analysis for each garolite tested at different temperatures. Figure 18, 19 and 20 show the crack propagation during shear puncture for Impact Resistance Garolite, High Temperature Garolite and Economical Garolite respectively.

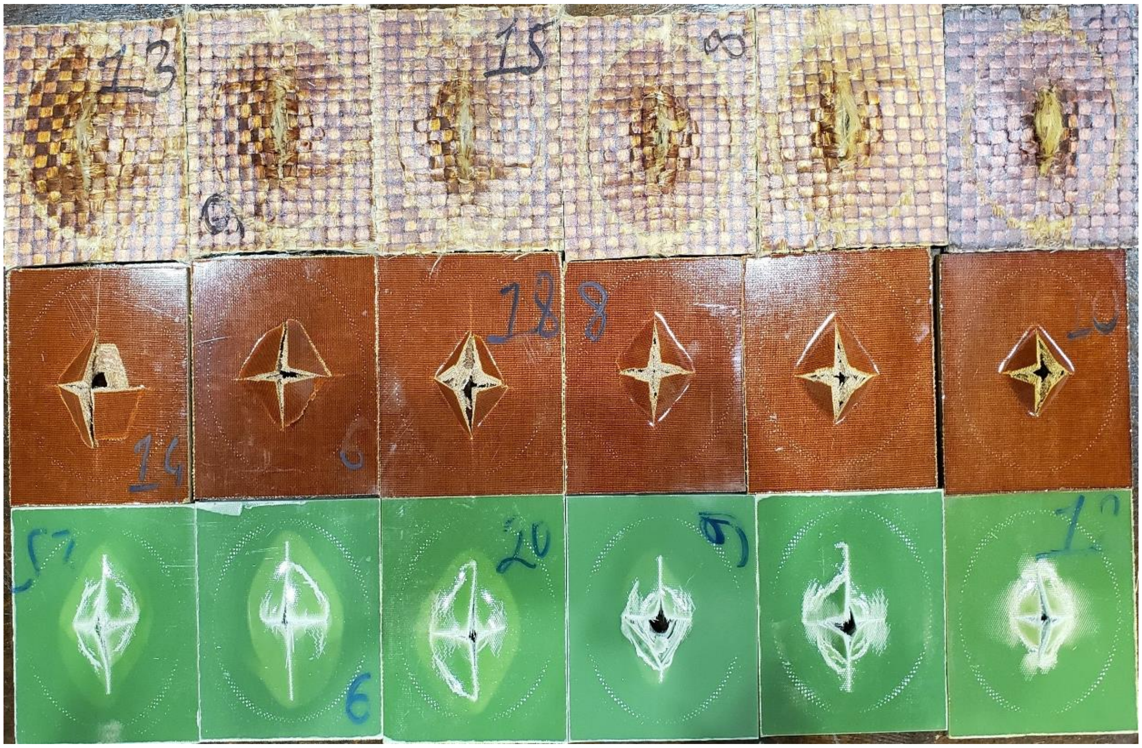

Fig. 17 Failure zone analysis of High Impact (top), Economical (middle) and High Temperature (bottom) Garolite at -10ºC, 25ºC, 50ºC,100ºC,150ºC and 200ºC from left to right respectively

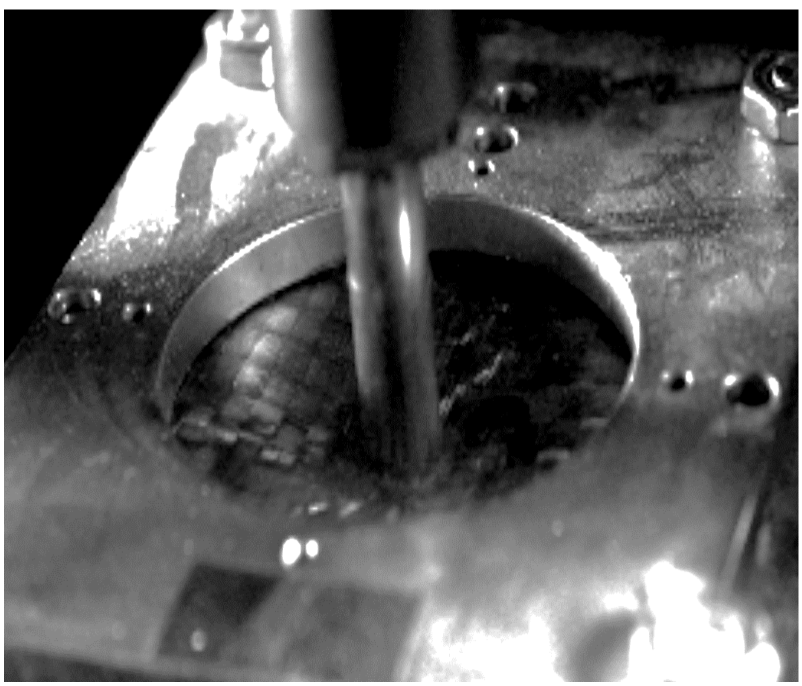

Fig. 18 Damage Propagation on High Impact Garolite at 50ºC right after impact

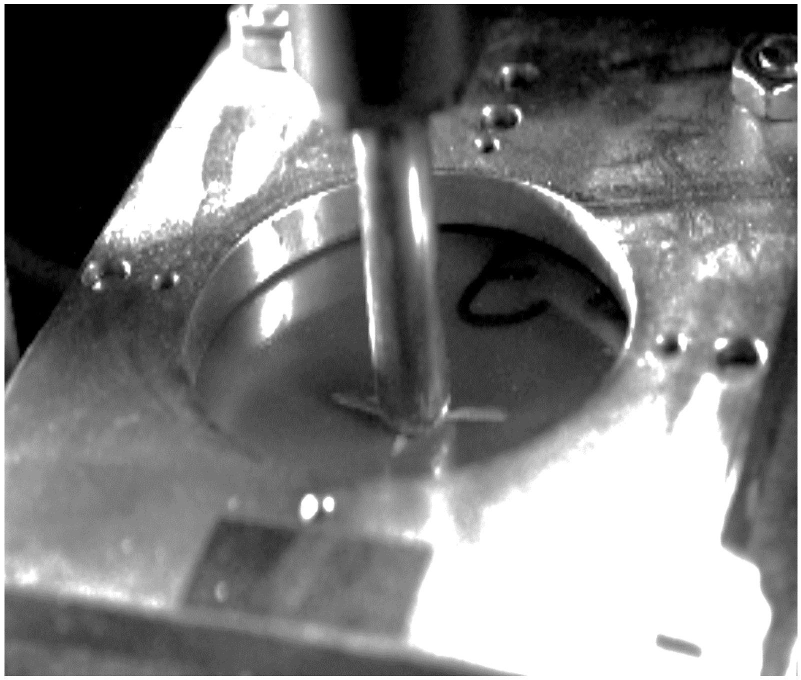

Fig.19 Damage Propagation on High Temperature Garolite at 50ºC right after impact

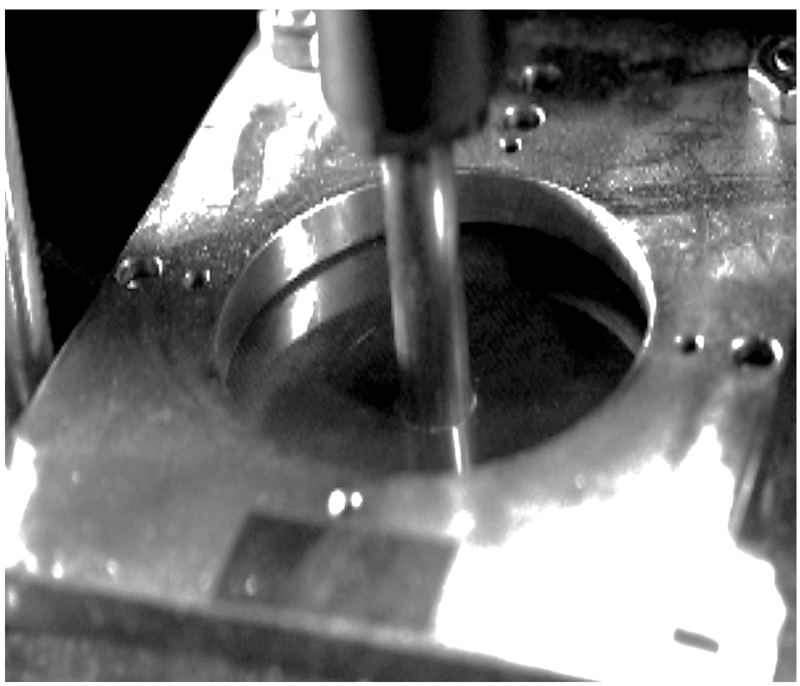

Fig. 20 Damage Propagation on Economical Garolite at 50ºC right after impact

Each Garolite behaves differently under the shear punch through. This is due to the materials used and how they are manufactured. The High Impact Garolite is a woven material and the layers were constructed by weaving each layer onto another. This provides extra support to the nearest particles and thus during the shear impact, a wide deflection was seen before delamination occurs. Due to this, it absorbs large amount of energy. Even after the shear punch through, the material responds well to the impact and absorbs a lot of energy after the damage propagation. The High Temperature Garolite shows some deflection before it starts cracking. This is due to the fact that, it is not a woven material and thus lack higher strength. The crack propagation after some deflection shows that the material does absorb some energy before damage propagation which is lower that the energy absorbed by High Impact Garolite but more than that of Economical garolite. The Economical Garolite absorbs the least amount of energy when compared to the other two. Minor cracks can be seen during the impact and the load tub goes through the sample. This solidifies the fact that it absorbs least amount of energy and there is little to no damage propagation making it very unreliable after failure.

CONCLUSION

In this study, the dynamic response of three different garolites, High Temperature G-11 Sheet, Impact Resistance Garolite E-glass and Economical Garolite Sheet were tested at 6 different temperatures, -10ºC, 25ºC, 50ºC, 100ºC, 150ºC and 200ºC. HIG showed the highest impact absorption whereas EG showed the lowest strength on impact. The total energy absorbed by HIG was roughly 12 times EG and roughly thrice as much as HTG. Similarly, the damage propagation energy of HIG was roughly 14 and 3 times than of EG and HTG. In general, for each garolite, as the temperature increased, the max load decreased starting at room temperature (25ºC), except for HIG which started decreasing after 50ºC. The max load increased from -12ºC to 25ºC as the materials tend to work best at the room temperature. Overall, the energy absorbed by HIG until max loading condition was around 11 times and 4 times the energy absorbed until max loading condition by EG and HTG respectively. The max impact load for HIG was respectively around 5 times and twice EG and HTG.

FUTURE WORK

This study provided some important information regarding the impact response of garolites when subjected to significantly higher temperatures. There are several future aspects of this experiment. Some inconsistencies were seen throughout the experiment which can be explored and refined in future works. Similarly, the dynamic response of these specimens can be tested using high impact velocity test and quasi static test. An investigation to fully understand the mechanism that causes the failure zone to decrease with the increase in temperature in garolite can be done in future works. These materials can be used for military applications such as making barricades and they weather out over time. So, studies regarding the low velocity and high impact test for weathered garolites can be done in future to better understand the change in dynamic response of these materials after they are weathered.

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