DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

THERMAL EFFECTS ON PUNCH SHEAR AND IMPACT BEHAVIORS OF LAMINATED COMPOSITE MATERIALS

by
Akim DJELE

July, 2019
İZMİR

THERMAL EFFECTS ON PUNCH SHEAR AND IMPACT BEHAVIORS OF LAMINATED COMPOSITE MATERIALS

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M.Sc. THESIS EXAMINATION RESULT FORM

We have read the thesis entitled "**THERMAL EFFECTS ON PUNCH SHEAR AND IMPACT BEHAVIORS OF LAMINATED COMPOSITE MATERIALS**" completed by **AKIM DJELE** under supervision of **PROF. DR. RAMAZAN KARAKUZU** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for degree of Master of Science.

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Akim DJELE

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ABSTRACT

Composites are widely used in many applications thanks to their high strength-weight ratio. Transverse loading can cause serious damage to composite materials such as delamination, fiber breakage and matrix cracking. In this study, the thermal effects on punch shear and low velocity impact behaviors of laminated composite materials were investigated.

The punch shear apparatus was fabricated in accordance with the previous researches and the quasi-static tests (QST) were performed by using Universal Shimadzu Tensile Testing Machine with the designed apparatus. Various speeds of crosshead as 1 mm/min., 10 mm/min., 20 mm/min, 40 mm/min and 60 mm/min were chosen for quasi-static tests. Low velocity impact (LVI) tests were carried out by using CEAST Fractovis Plus impact test machine at four different impact energies, 20J, 30J, 50J, and 80J. S2 glass/epoxy and hybrid carbon-kevlar/epoxy composite specimens with dimensions of 100x100 mm were used for both QST and LVI tests. Flat-nose and hemispherical nose impactors with a cylindrical punch diameter of 12.70 mm were mounted to the test machines. The tests were firstly performed at room temperature (23°C) and after with varied degree of temperature namely 40°C ,60°C and 80°C, in order to observe the effects of the temperature.

After the experiments, the load-displacement graphs were plotted and the absorbed energy determined. The results of quasi-static punch shear test were compared to those of the low-velocity impact test and conclusion drawn.

Keywords: Composites materials, punch shear test, low velocity impact test, S2 glass/epoxy, hybrid carbon-kevlar/epoxy

TABAKALI KOMPOZİT MALZEMELERİN ZIMBA KAYMA VE DARBE DAVRANIŞLARINA TERMAL ETKİLER

ÖZ

Kompozit malzemeler sahip oldukları yüksek mukavemet-ağırlık oranları sayesinde birçok uygulamada yaygın olarak kullanılmaktadır. Enine yükleme, delaminasyon, elyaf kırılması ve matris çatlaması gibi kompozit malzemelerde ciddi hasarlara neden olabilmektedir. Bu çalışmada, tabakalı kompozit malzemelerin zımba kayma ve darbe davranışları üzerine sıcaklığın etkisi incelenmiştir.

Zımba kayma test aparatı, önceki araştırmalara uygun olarak üretilmiş ve yarı-statik testler (QST) Shimadzu evrensel test cihazı ile birlikte tasarlanmış aparatla kullanılarak yapılmıştır. Yarı statik testler için 1 mm / dak, 10mm / dak, 20mm / dak, 40mm / dak ve 60mm / dak test hızları seçilmiştir. CEAST Fractovis Plus darbe test cihazı kullanılarak 20J, 30J, 50J ve 80J olmak üzere dört farklı darbe enerjisinde, düşük hızlı darbe (LVI) testleri yapılmıştır. Hem QST hem de LVI testi için 100x100 mm boyutlarında S2 cam / epoksi ve hibrid karbon-kevlar / epoksi kompozit numuneler kullanılmıştır. Test cihazına, 12,70 mm çapa sahip düz ve yarı küresel uçlu silindirik zımba monte edilmiştir. Testler, ilk önce oda sıcaklığında (23°C) ve sonra sıcaklığın etkisini incelemek için 40°C, 60°C ve 80°C sıcaklıklarda yapılmıştır.

Yapılan testler sonucunda kuvvet-çökme eğrileri çizilmiş ve absorbe edilen enerji değerleri elde edilmiştir. Statik ve dinamik testlerin sonuçları karşılaştırılarak aralarında bir ilişki kurulmuştur.

Anahtar kelimeler: Kompozit malzemeler**,** zımba kayma testi, düşük hız darbe testi, S2 cam/epoksi, hibrit karbon-kevlar/epoksi

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CHAPTER ONE
INTRODUCTION

1.1 Overview

Composites are widely used in many applications where lightweight damage tolerant structures are demanded. In recent years, fiber reinforced polymer composite materials have been replaced metals in structural application thanks to their superior properties with low weight. Carbon and glass fiber reinforced polymer materials with their high strength / weight ratio have made these materials attractive for the production of new generation materials. However, polymer-based composite materials are highly sensitive to transverse load. Therefore, many researchers have investigated the impact behavior and damage of composites in order to understand those mechanisms. Nevertheless, the transverse impact test is a very laborious and expensive form of testing. One of the much simpler and cheaper way is quasi-static tests which is the best tools used to characterize impact events providing. Bulut, Erkliğ &Yeter (2016) considered low velocity impact behavior as quasi-static to be neglected dynamic effect. The composite materials and structures are subjected to various loading conditions during their lifetime. Among these, one of the most critical form of loading is the transverse impact load due to the laminated nature of these structures. When exposed to a low velocity impact, the behavior of the composites becomes very complex due to various events such as fiber breakage, delamination, deformation, and failure of plugging. In addition, in many studies, the transverse impact behavior of laminated composites under low and high temperature has been investigated.

Composite materials have many advantages over more common materials. They exhibit the best quality of their components that individual materials do not possess. Their biggest advantage is that they are very strong. Some of the properties such as strength related to weight and stiffness, corrosion resistance, wear resistance, attractiveness; fatigue life, design flexibility temperature dependent behavior, thermal conductivity and acoustical insulation can be improved by forming a composite material. (Jones, 1999) Besides its advantages, we can also enumerate some disadvantages of composites material such as delamination, high cost, complex fabrication, damage under transverse impacts.

Various tools may fall on a composite structure during production or maintenance. In this case, although the impact velocities are small, serious damage can occur due to the large mass of the projectile. Various damages, such as matrix cracks, delamination, fiber fracture, fiber–matrix debonding and fiber pullout can occur when a composite laminate is exposed to low velocity impact with sufficient energy. These damages result in a significant reduction in structural strength, leading to an increase in damage and final fracture. Thus, the transverse impact response of fiber-reinforced polymer composites has long been an important area of research due to reasons as mentioned above. Numerous experimental studies have been reported in the literature for these topics. Some of the relevant studies are presented below.

Composite materials are likely to become more ductile or more brittle when they are submitted to work at low or high temperature, which can affect their performance. The impact response of woven carbon/epoxy (Mitrevski, Marshall, & Thomson 2006), and of woven glass/epoxy laminates were examined by using flat, hemispherical, ogival and conical impactor shapes. Caprino et al. (2004) performed the effect of impact velocity, mass, and energy on glass/aluminum composite laminates. Icten, Atas, Aktas, & Karakuzu (2009) investigated the low temperature effect on impact response of E-glass fiber reinforced epoxy composites. The impact behavior of laminated glass/epoxy composites was examined at several temperatures experimentally. As a result of experimental tests, the ambient temperature affected the impact response of composite materials was observed.

Aktas, Karakuzu & Içten (2011), investigated the thermal impact behavior of glass/epoxy-laminated composite plates. The experiments were conducted at both room temperature and high temperature. Result showed that when temperature is increasing the mechanical properties such rigidity and strength are lost. Moreover, by the impact energy increased, the increase of maximum contact force is observed and when the temperature increases, its decrease is observed. Caprino et al. (2003) carried out quasi-static tests on circular carbon fiber reinforced plastic plates of various thicknesses. The experimental results demonstrated that the penetration energy was substantially unaffected by the loading speed.

Liang et al. (2015) performed the progressive damage in satin weave carbon/epoxy composites under quasi-static punch-shear loading in order to determine the possible damage during a penetrating impact event. It was found that the final failure was caused by major delamination and fiber breakage due to shear and tensile stresses developed during the QS-PST tests. Xiao, Gama & Gillespie (2007) examined the progressive damage and delamination in plain weave S2 glass/SC-15 composites under quasi-static punch-shear loading. Load–unload tests were carried out to find the progression and level of damage including the corresponding displacements at which these happen for a several of laminate. It was determined that the main damage mechanisms are delamination and fiber breakage due to shear and tension.

Sadeghi & Pol (2019) investigated behaviors of glass/epoxy laminate composites reinforced with carbon nanotubes under quasi-static punch shear test. In that study the tensile characteristic properties of epoxy matrix and glass/epoxy laminate composite and the effect of indenter form on quasi-static punch shear properties of glass/epoxy laminate are investigated.

Salehi, Hassani, Haftchenari, & Hinton (2001), conducted quasi-static and impact tests to characterize glass-epoxy under low, room and high temperatures. Results showed that the temperature decreases the maximum strength in quasi-static tests. Kubota, Bazle A. Gama, & Yarlagadda (2006) investigated the impact and damage behaviors of Kevlar-carbon/epoxy composites. They conducted quasi-static punch shear tests and low velocity impact tests on M30/8551 carbon/epoxy baseline laminates, thermoplastic polyurethane (TPU) bonded M30/8551/Kevlar, Ionomer bonded M30/8551/Kevlar, and Epoxy adhesive bonded M30/8551/Kevlar composite specimens. It was observed that in the rear surface of the Baseline specimen failed terribly as inside the Kevlar skin the rear face breakage was contained by the TPU, ionomer, and epoxy bonded Kevlar. Debonding between the Kevlar layer and the

Baseline composite specimen was observed by ionomer specimen but no debonding showed by the TPU and Epoxy bonded specimens.

Fernandes, Junior, Filho, Guedes & Porto (2016) have studied ballistic impact and quasi-static punch shear behaviors of polymer composites. In that study the composites specimen with different layers were submitted to both tests. The 10 layers woven was found to be the best ballistic performance.

In our study, the primary objective is to investigate experimentally the thermal effects on punch shear quasi-static test and low velocity impact behaviors of two different laminated composite materials namely the S2 glass/epoxy and hybrid carbon-kevlar/epoxy. In this context, contact force-deflection and absorbed energy- impact energy diagrams have been obtained for impact energy at each level for different impact velocity and different loading speed of quasi-static test. From the obtained results, discussions have been done and comparisons made between the two different types of laminates composites materials in order to find a relationship between the materials.

CHAPTER TWO
MATERIALS AND METHODS

2.1 Introduction

Our experiments have been carried out in the laboratory of the Mechanical Engineering Department of Dokuz Eylül University precisely in Composites Material laboratory.

The experiments were performed with the composite materials. So, the composite materials have been manufactured by using hybrid kevlar-carbon/epoxy, S2 Glass/epoxy material by the vacuum assisted resin infusion method (VARIM). Quasi-static punch shear test apparatus has been conceived and equipped on the Universal Shimadzu tensile test machine in order to perform the compression quasi-static shear test on the composite. Ceast Fractovis-plus impact test machine also were used in order to perform the low velocity impact test on the specimen. The method of different test fixtures is developed below.

2.2 The Vacuum Infusion Method

The vacuum assisted resin infusion method (VARIM) is a technique that uses vacuum pressure to drive resin into a laminate. Materials are laid dry into the mold and the vacuum is applied before resin is introduced. Once a complete vacuum is achieved, resin is literally sucked into the laminate via carefully placed tubing. This process is aided by a collection of supplies and materials.

For the manufacturing of the laminate composite material 18 layers of S2 glass and 12 layers of hybrid carbon-kevlar are used as fibers (Figure 2.1). The areal densities of S2 glass fabric and hybrid carbon-kevlar fabric are 190 g/m^2 and 210 g/m^2, respectively. The nature of the matrix used is epoxy thermoset resin. 30% of curing agent and 100% of epoxy have been used in the preparation of the matrix component.

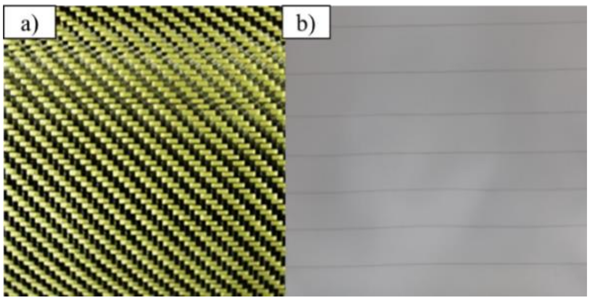


Figure 2.1 a) Hybrid kevlar-carbon fiber b) S2 glass fiber (Personal archive, 2019)

➢ The reinforcement materials are laid-up dry in the mold (Figure 2.2). This is done by hand and provides the opportunity to precisely position the reinforcement. Peel ply are placed above the reinforcement material and flow medium are placed above the peel ply.

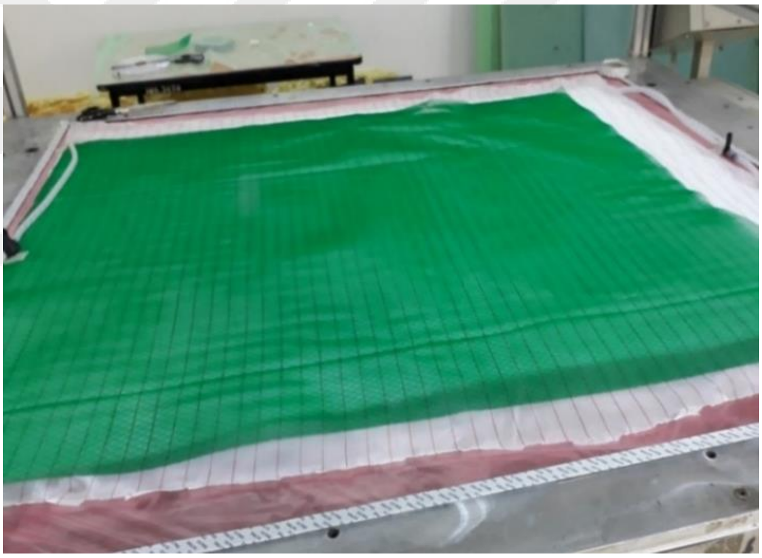


Figure 2.1 Laying down of fiber layers (Personal archive, 2019)

➢ The vacuum bagging the final layer is applied over the top of all the other layers. Once all the components are ready, vacuum pump attached, the resin mixed in a bucket, it is catalyzed and infused through vacuum pressure into the laminate (Figure 2.3). The resin progressively fills up the laminate outwardly until it is saturated. After that the resin line is unfastened the infusion is considered done. In Figure 2.4, the final composite product obtained after removing the bagging material. The specimen has been cut on 100 mm x 100 mm dimensions with 3.27 mm and 3.03 mm of the thicknesses of hybrid carbon-kevlar/epoxy and S2 glass/epoxy specimen, respectively. Their weight is 46 g for hybrid carbon-kevlar/epoxy and 56.6 g for S2 glass/epoxy.

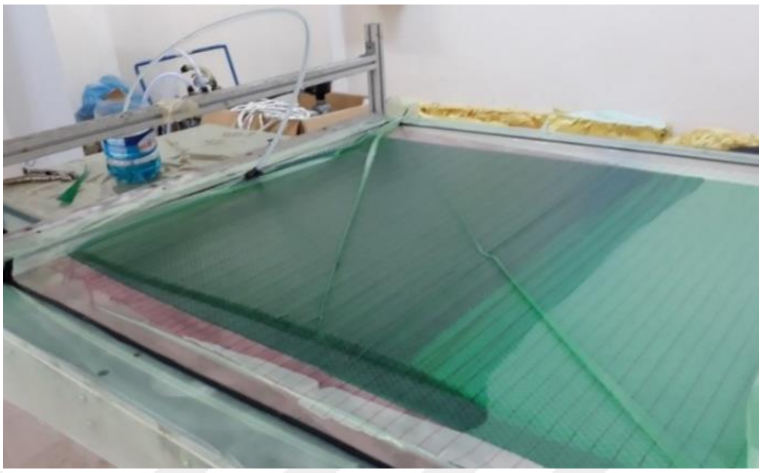


Figure 2.2 Resin infused through vacuum pressure (Personal archive, 2019)

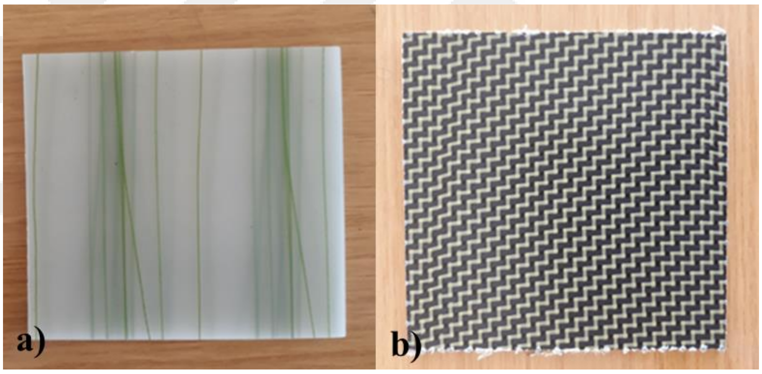


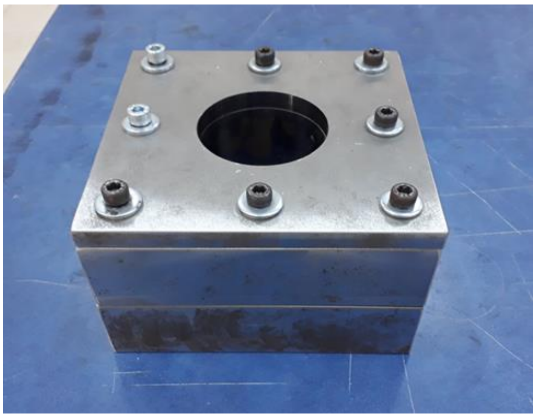
Figure 2.3 a) S2 Glass/Epoxy b) Hybrid Carbon-Kevlar/Epoxy (Personal archive, 2019)

2.3 Quasi-static punch shear test

Quasi-static punch shear test (QS-PST) apparatus has been conceived in accordance with custom-made fixture QS-PST used for the researches. In Figure 2.5, a QS-PST fixture consists of a square support-plate (50.80-mm thickness) with a circular hole (76 mm diameter) at the center, a relatively thin cover-plate (12.70-mm thick) with a central hole similar to the support plate, and two cylindrical punches with diameter of 12.7 mm one flat tip, the other hemispherical tip. An additional rectangular bottom support plate (50.80-mm thickness) with a square hole (100 mm x 100 mm) at the center was also used in addition to the support. The full dimensions of our device are given in the appendix.

Quasi-static punch shear test apparatus has been equipped on the Universal Shimadzu tensile–compression test machine in order to perform the compression shear test on the laminate. The composite specimen with dimensions of 100 mm x 100 mm were clamped between the cover plate and middle support plate with a diameter of 25.40 mm hole in the center, as shown in Figure 2.5. The tests have been conducted by applying a crosshead displacement at different rates of 1mm/min, 10 mm/min, 20 mm/min, 40 mm/min and 60 mm/min on Universal Shimadzu tensile–compression test machine with maximum load of 100 kN. No dynamic effects were likely to happen on the material behavior at that rate. The load and crosshead displacement are recorded and read during the loading process.

a)



b)

Figure 2.4 a) Tensile Testing Machine with punch-shear test apparatus b) Quasi-Static Test Apparatus (Personal archive, 2019)

Punch shear strength is obtained by using the following equation:

$$\tau_{PSS} = \frac{P_{max}}{\pi \mathrm{dt}} \tag{2.1}$$

Where P_{max} is the maximum force, d is the diameter of the flat punch, and t is the thickness of the specimen.

2.4 Low velocity impact test

Ceast Fractovis-plus impact test machine (Figure 2.6) is used to perform the low velocity impact test on the specimen. The machine is designed to deliver variable energies with the optional high-energy system. It includes many features that make testing easy and can receive many options, such as a temperature chamber or high-energy option. The drop pit works with impact testing software and a data acquisition system to simplify the analysis of the results.

Two types of indenter as impactor are used to strike the specimens, the flat-nose and hemispherical nose impactor with 12.7 mm diameter and attach to maximum loading capacity of 22.4 kN piezoelectric force transducer. The impactor has a total falling mass of 5 kg (impactor and crosshead included). In order to avoid the repeated impacts on the specimen an anti-rebounding system exists in the test machine. Maximum potential energies 1800J is likely to be generated by the drop weight test machine through the additional mass, which increases the speed of the impactor up to 24 m/s. The test machine has a built-in heater and cooler system that is connected to a computer via the data acquisition system (DAS) which allowed us to perform the tests in different temperatures conditions (40°C, 60°C, 80°C) (Calik, 2010).

Figure 2.5 Ceast Fractovis-Plus impact test machine (Personal archive, 2019)

In each impact test, three composite specimens (100 mm x 100 mm) were struck and average result taken. The impact energies used for this study were selected 20J, 30J, 50J and 80J. Impact results such as contact force versus deflection and absorbed energy versus impact energy were obtained by being sent through DAS and downloaded to a computer for graphical processing.

CHAPTER THREE
RESULTS AND DISCUSSIONS

3.1 Low velocity impact tests (LVI)

Impact energy (*Ei*) and absorbed energy (*Ea*) are two essential factors to evaluate impact response of composite structures. The impact energy is defined as the energy absorbed by a specimen without fracture. The absorbed energy is the quantity of energy consumed by an impactor for full penetration into a composite. The relationship that exists between impact energy and absorbed energy is called "energy profile" (Figure 3.1).

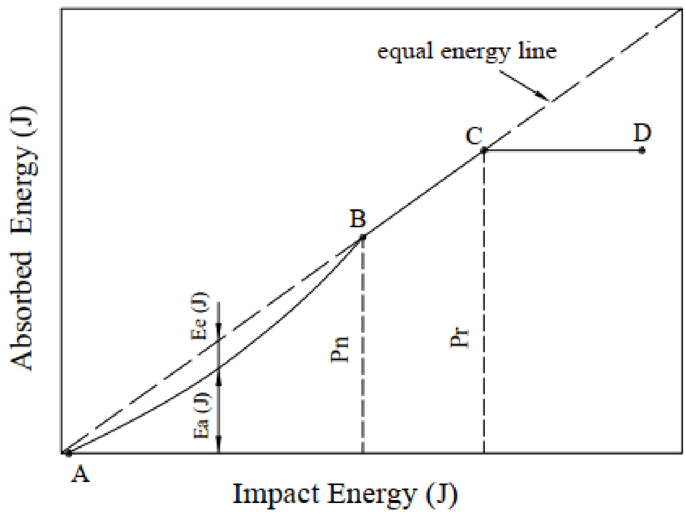


Figure 3.1 Energy profile diagram of a composite structure (Aktaş, 2007)

(Ei) stand for the impact energy, and (Ea) stand for the absorbed energy while Pn and Pr represent the penetration and perforation thresholds respectively. Three main regions AB, BC and CD are represented on this diagram. AB represents the rebounding case, BC represents the penetration case, and CD correspond to the perforation case (Aktaş, 2007).

The results of low velocity impact on the specimen can present three different sorts of interpretations namely rebounding, penetration and perforation. Therefore, with the graphs as contact force versus deflection, impact energy/quasi-static velocity versus absorbed energy it was quite possible to understand the results.

3.1.1 LVI results with flat nose (F) penetrator

Figures 3.2-3.3 represent the flat nose diagram of force-deflection for both specimen composite in impact test at room temperature 23°C for flat nose. It is observed from hybrid carbon-kevlar/epoxy specimen (HY) that rebounding exists in the composite specimen with 20J impact energy. Contact force increases by increase of impact energy, penetration occurred at 30J, 50J, and 80J while rebounding occurs in composite S2 glass/epoxy (S2) specimens with 20J and 30J impact energy. Contact force increases with increase of impact energy. After penetration, contact force does not change significantly. Penetration and perforation exist at 50J and 80 J, respectively.

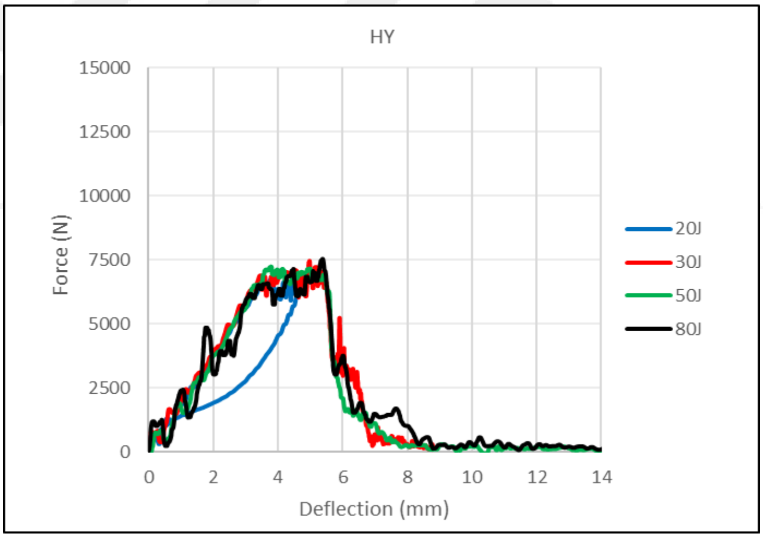


Figure 3.2 Force-deflection diagrams for Hybrid carbon-kevlar/epoxy composite in impact test at 23°C

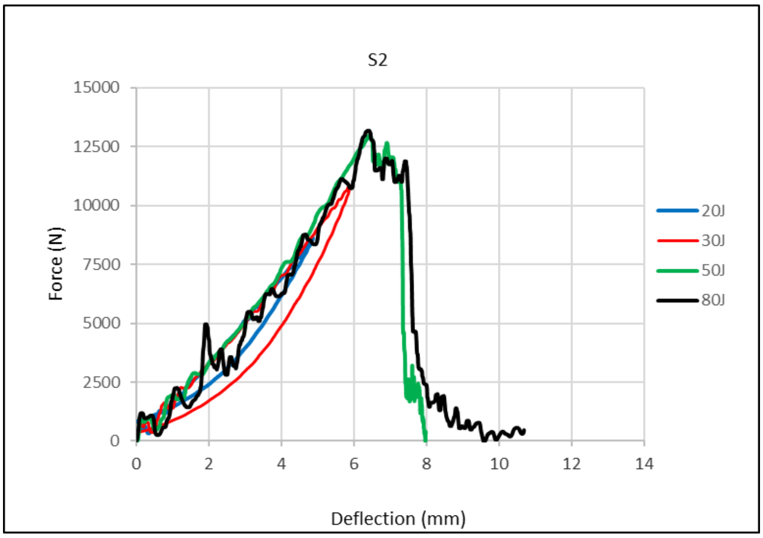


Figure 3.3 Force-deflection diagrams for S2 glass/epoxy composite in impact test at 23 °C

Front and back side views of some specimens are presented in Figure 3.4. As it can be seen at room temperature with flat nose the major mode of failure occurred such as delamination, penetration and perforation. At low energy the both specimens underwent rebounding but the behavior were not the same when the impact energy increase progressively. The increase of impact energy causes fiber breakage.

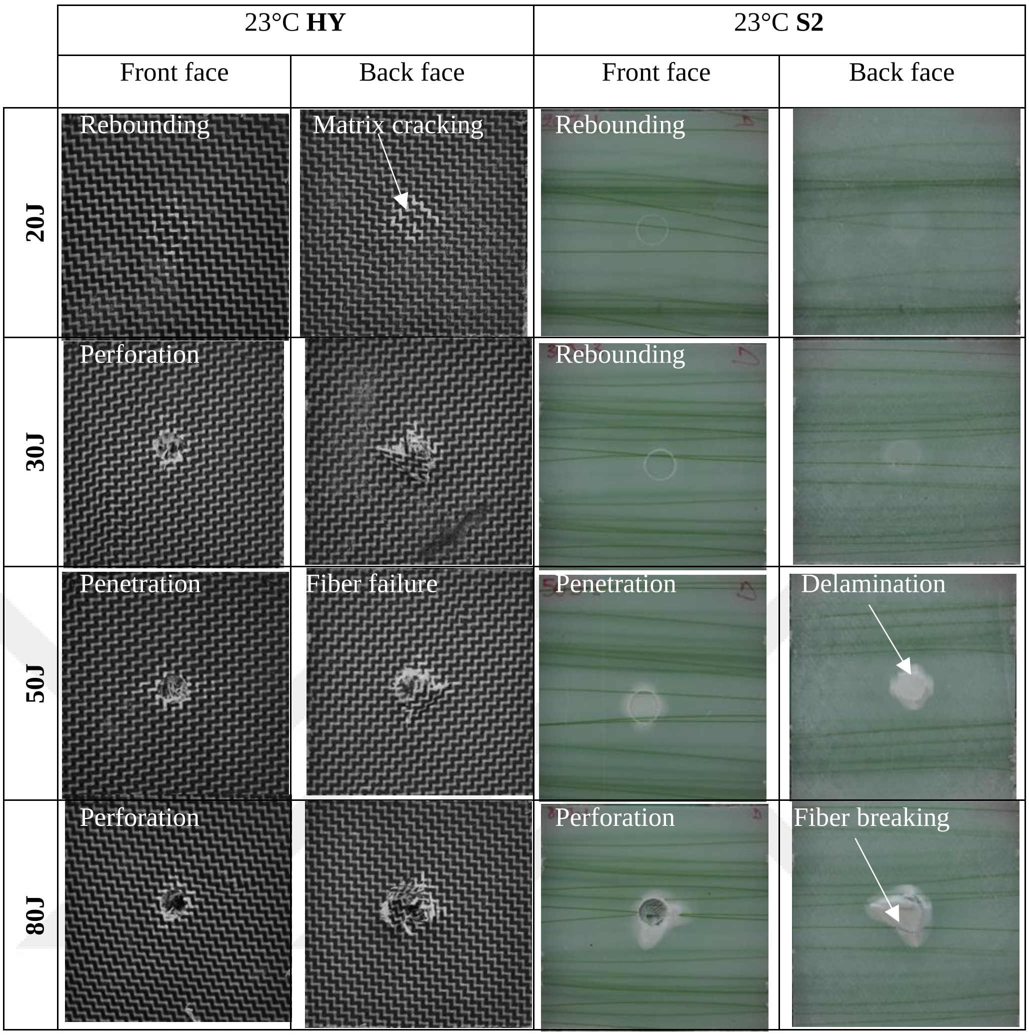


Figure 3.4 Flat nose LVI test specimens with 20J, 30J, 50J and 80J impact energy for 23°C

The results of contact force-deflection flat nose diagram at 40^{o}C temperature are presented in Figures 3.5-3.6. With the hybrid carbon-kevlar/epoxy specimen, it is noticed a rebounding at 20J but full penetration of the specimens at the others energies. Maximum contact forces remain almost the same at the all level of energies. However, in S2 glass/epoxy specimen contact force increases by increase of impact energy but the specimens resisted to the penetration because of the rebounding except for the perforation that occurs in 80J. The maximum contact force of S2 glass reinforced composites is higher than hybrid reinforced composites for all impact energies. An opposite trend was observed in the deflections.

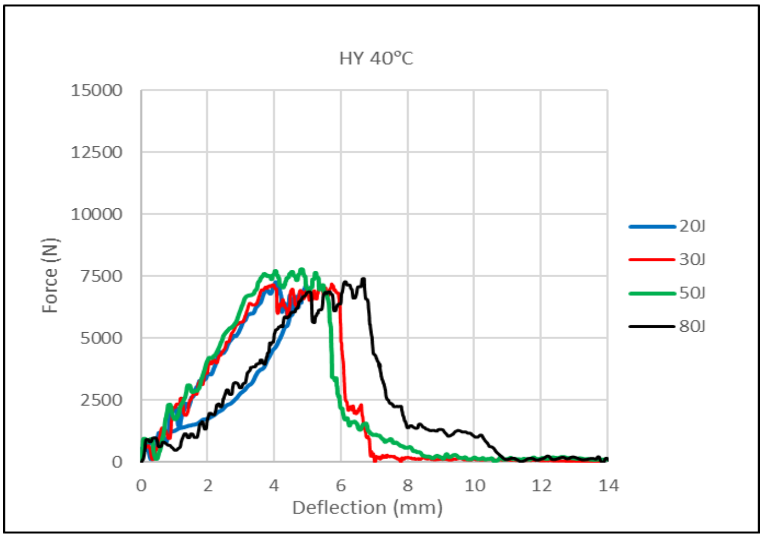


Figure 3.5 Force-deflection diagrams for hybrid carbon-kevlar/epoxy composite in impact test at 40 °C

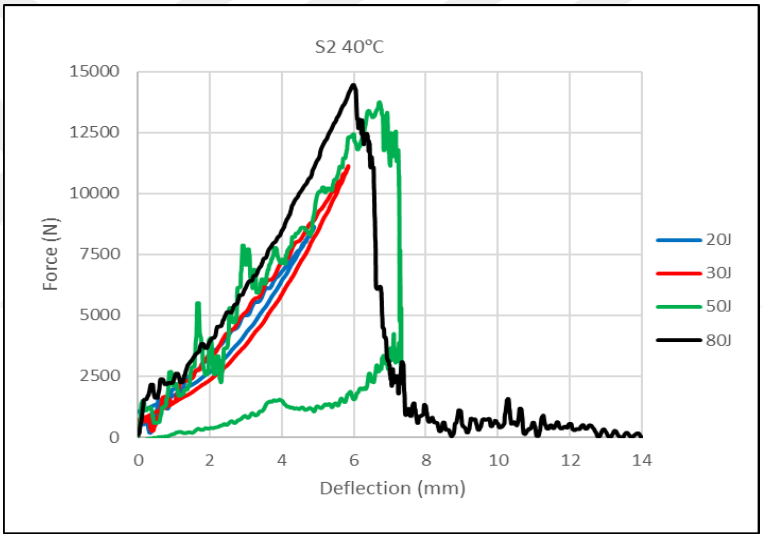


Figure 3.6 Force-deflection diagrams for S2 glass/epoxy composite in impact test at 40 °C

Figures 3.7-3.8 represent the flat nose force-deflection diagram at 60°C temperature of the specimens. The hybrid carbon-kevlar/epoxy specimen presents an increase of contact forces while the impact energy increases. For 20J and 30J, a rebounding is observed and perforation occurred in the specimen at 50J and 80J. It has been observed in the S2 glass/epoxy specimen that the contact forces have increased while the impact energy increases. The rebounding case occurred at first three energies applied (20J, 30J, 50J) while a perforation occurred in the specimen at the last energy 80J.

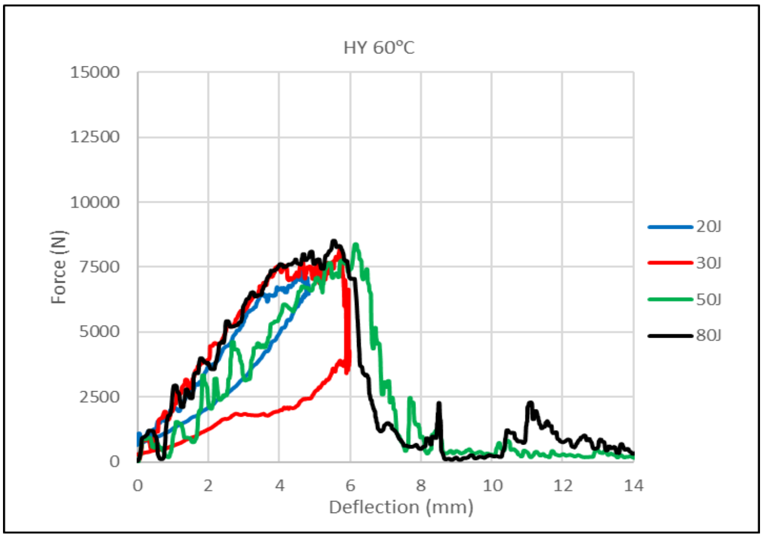


Figure 3.7 Force-deflection diagrams for hybrid carbon-kevlar/epoxy composite in impact test at 60 °C

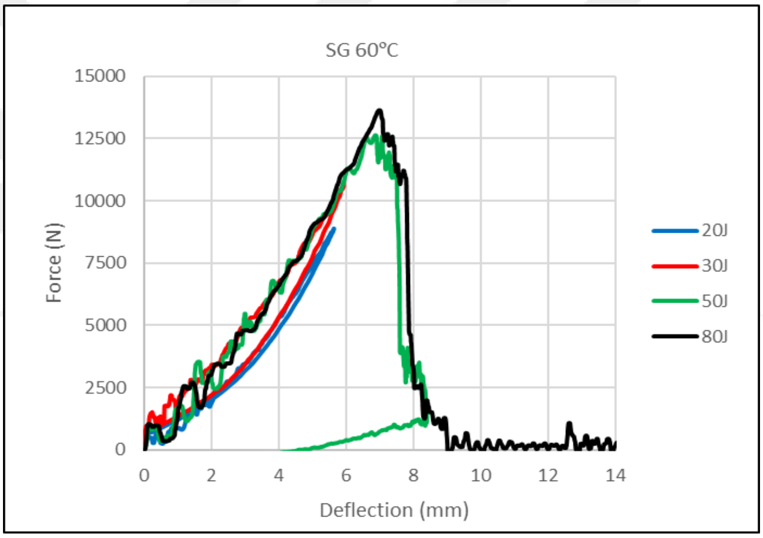


Figure 3.8 Force-deflection diagrams for S2 glass/epoxy composite in impact test at 60 °C

The results of flat nose force-deflection diagram at 80°C temperature are presented in Figures 3.9 and 3.10. It can be observed with the hybrid carbon-kevlar/epoxy specimen that the increase of the impact energy still implies the increase of the contact forces but only perforation occurred at 50J and 80J. S2 glass/epoxy specimen has showed the same observations but only perforation happened at 80J.

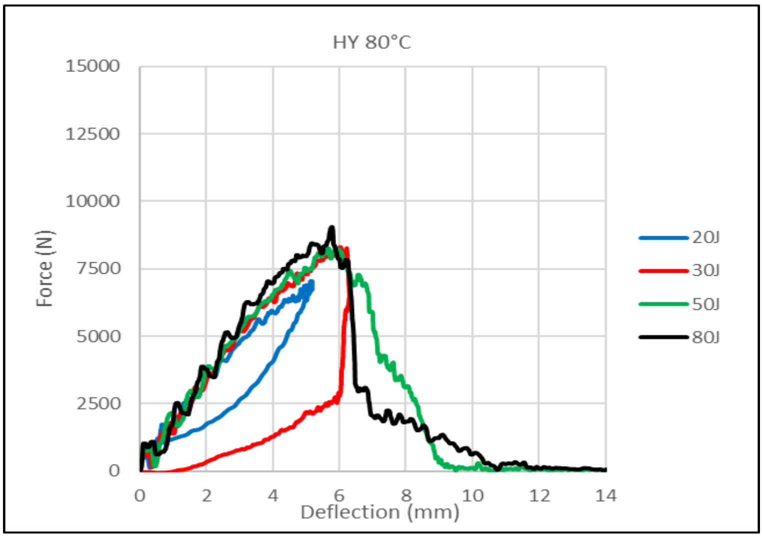


Figure 3.9 Force-deflection diagrams for hybrid carbon-kevlar/epoxy composite in impact test at 80 °C

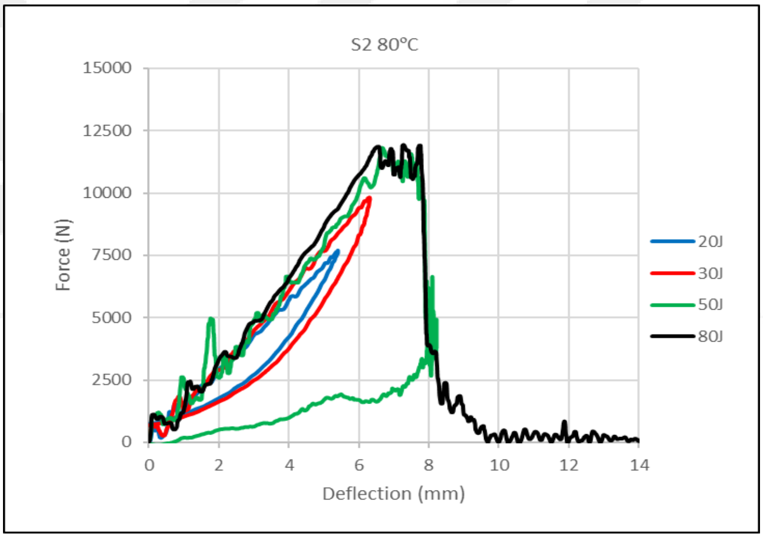


Figure 3.10 Force-deflection diagrams for S2 glass/epoxy composite in impact test at 80 °C

In Figure 3.11 which presents the temperature effects of a chosen impact energy 50J under the flat nose punch it is noticed that all the specimens underwent perforation with hybrid carbon/epoxy specimen. However different kind of failures have been noticed with S2 glass/epoxy specimen.

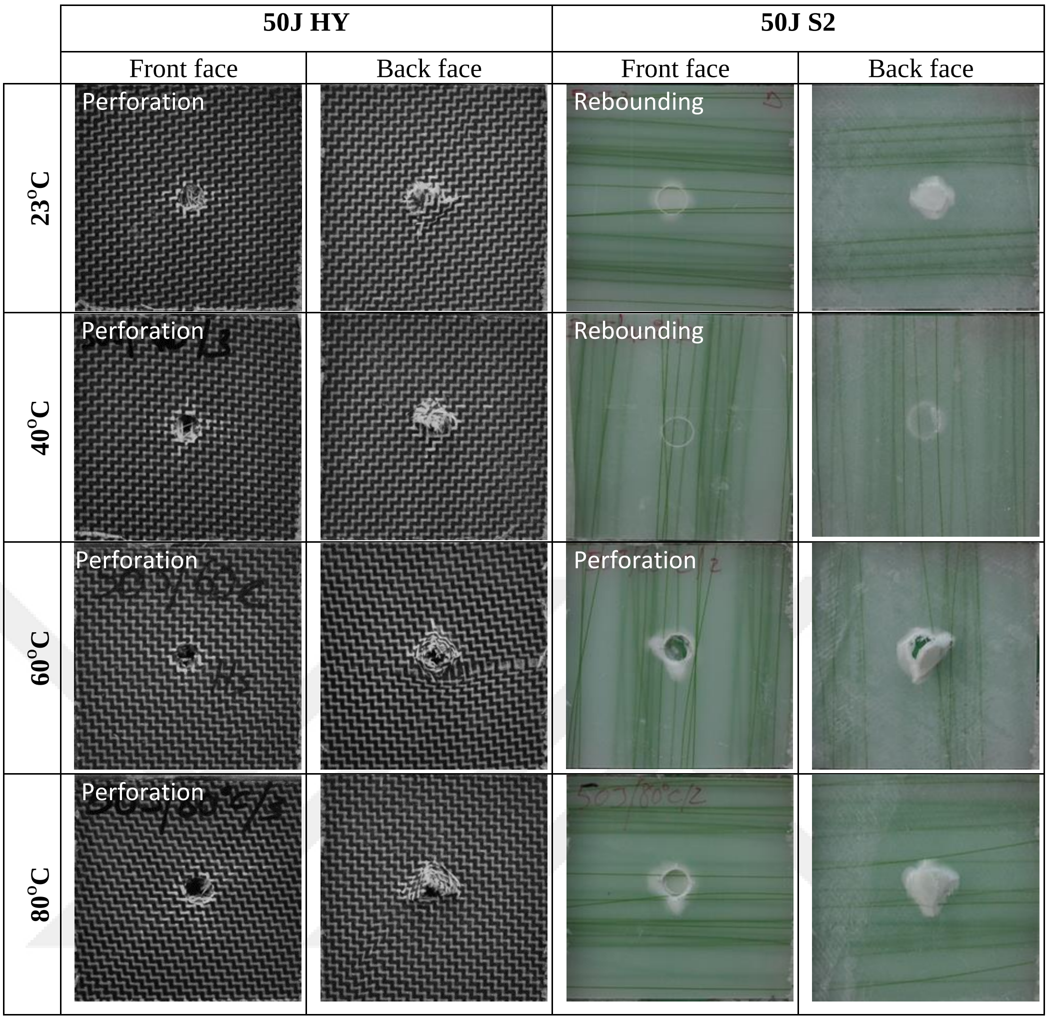


Figure 3.11 Flat nose LVI test specimens with 23ºC, 40ºC, 60ºC and 50ºC for 50J impact energy

Figure 3.12 presents the 80°C temperature effect of a chosen impact energy 80J under the flat nose punch. Most of the mode failure occurred are delamination, penetration and perforation.

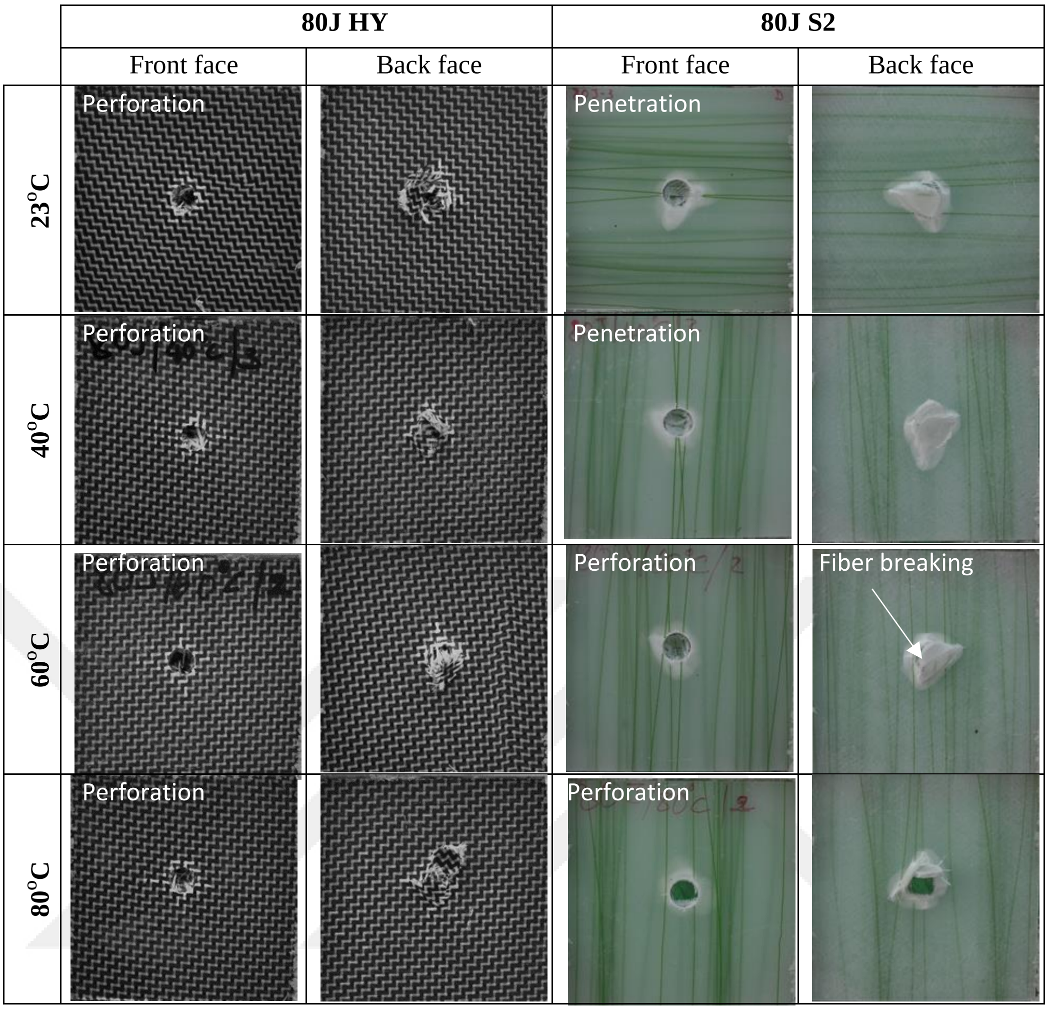


Figure 3.12 Flat nose LVI test specimens with 23ºC, 40ºC, 60ºC and 80ºC for 80J impact energy

3.1.2 LVI results with hemispherical nose (HS) penetrator

Figures 3.13 and 3.14 show the result of force-deflection diagram of both specimens at room temperature 23 °C. It is observed that a general decrease of contact force occurs by changing the penetrator tip while, in all cases the displacement increased. With hybrid carbon-kevlar/epoxy specimen, only the rebounding occurs with the 20J impact energy on specimen, the rest of impact energies applied causes the perforation of the specimen. However, with S2 glass/epoxy specimen a rebounding at 20J and 30J is observed and a perforation occurred at 50J and 80J.The contact forces are almost the same at 50J and 80J.

Figure 3.13 Force-deflection diagrams for hybrid carbon-kevlar/epoxy hemispherical nose in impact test at 23 °C

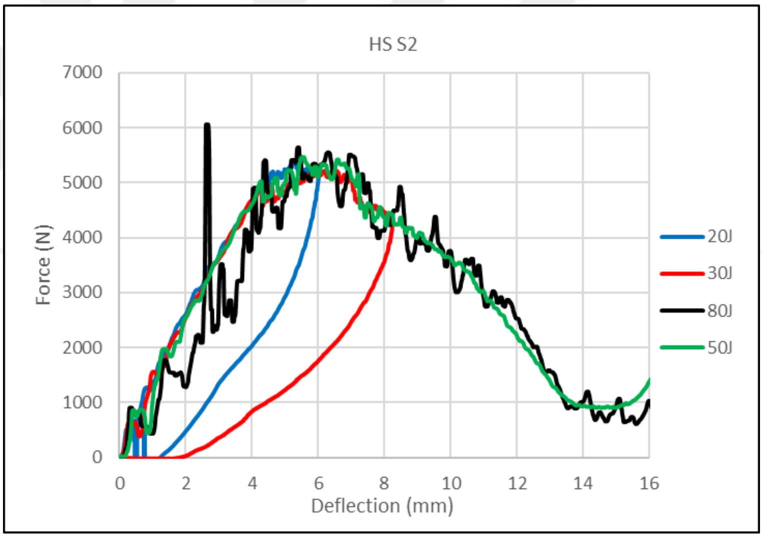


Figure 3.14 Force-deflection diagrams for S2 glass/epoxy hemispherical nose in impact test at 23 °C

Figure 3.15 presents some specimens tested with the hemispherical nose.at room temperature under the all different impact energies. As it can be seen the major mode of failure occurred such as delamination, penetration and perforation. At low energy the both specimens underwent rebounding but the behavior were not the same when the impact energy increase progressively. The increase of impact energy causes fiber breakage.

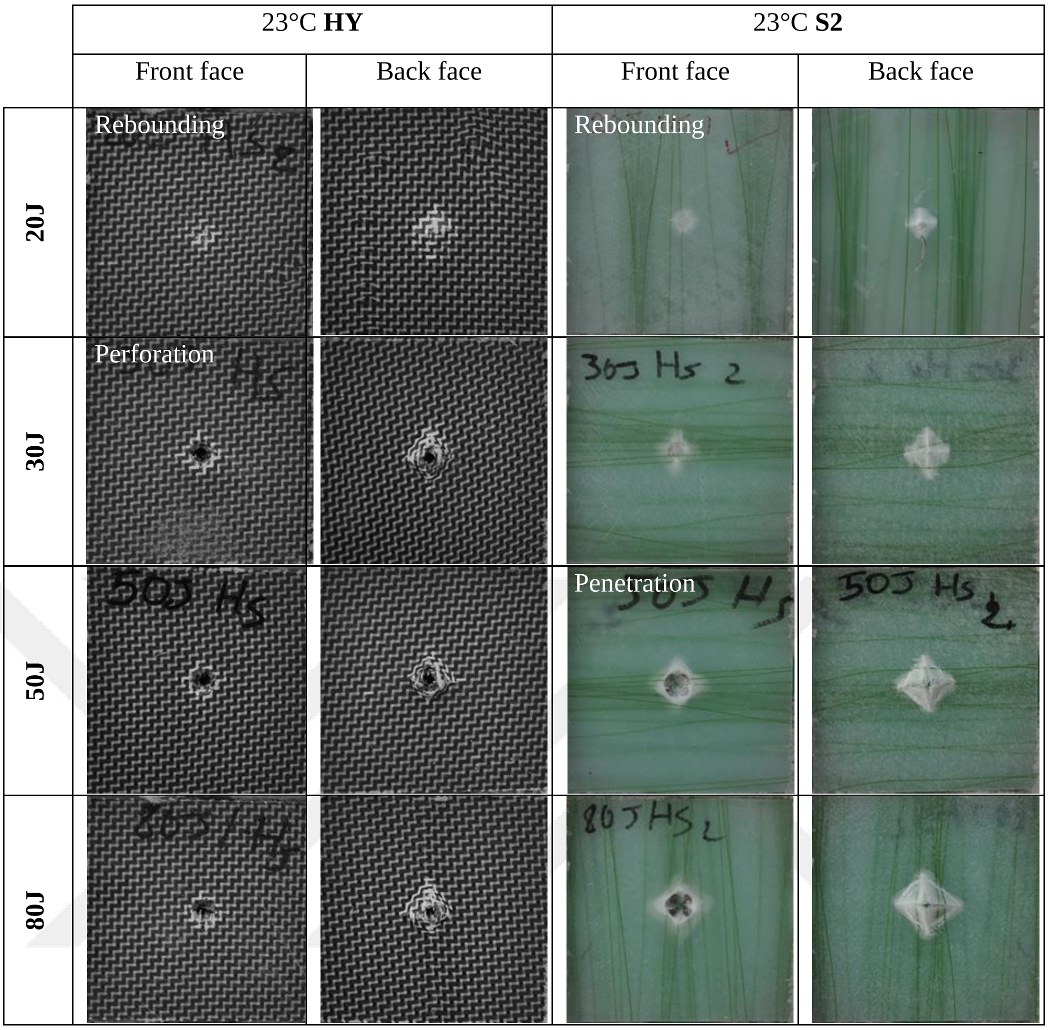


Figure 3.15 Hemispherical nose LVI test specimens with 20J, 30J, 50J and 80J impact energy for 23°C

At 40 °C temperature for the force-deflection curve, the results are as presented as shown in Figure 3.16. The hybrid carbon-kevlar/epoxy specimen underwent the rebounding at 20J and the perforation at 30J, 50J, and 80J. A slight increase of contact force occurs when impact energy increases. While, under the same condition with S2 glass/epoxy specimen the results as illustrated in Figure 3.17, almost the same observation has been made except that a rebounding occurs also at 30J.

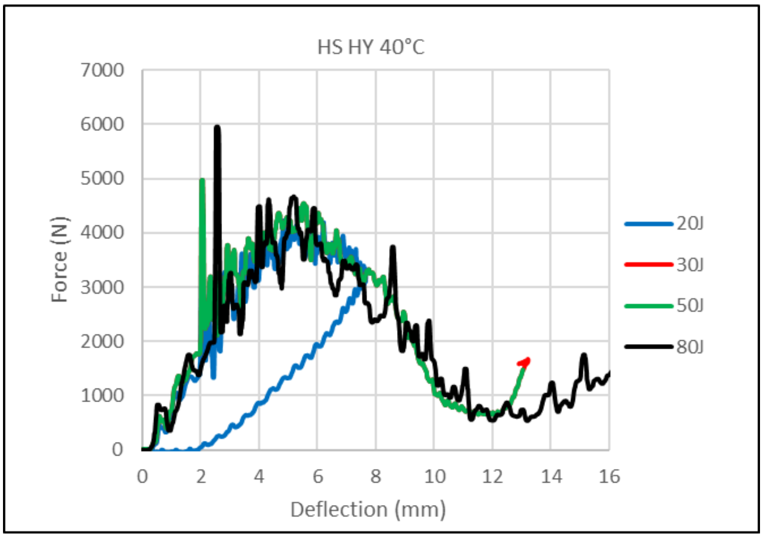


Figure 3.16 Force-deflection diagrams for hybrid carbon-kevlar/epoxy hemispherical nose in impact test at 40 °C

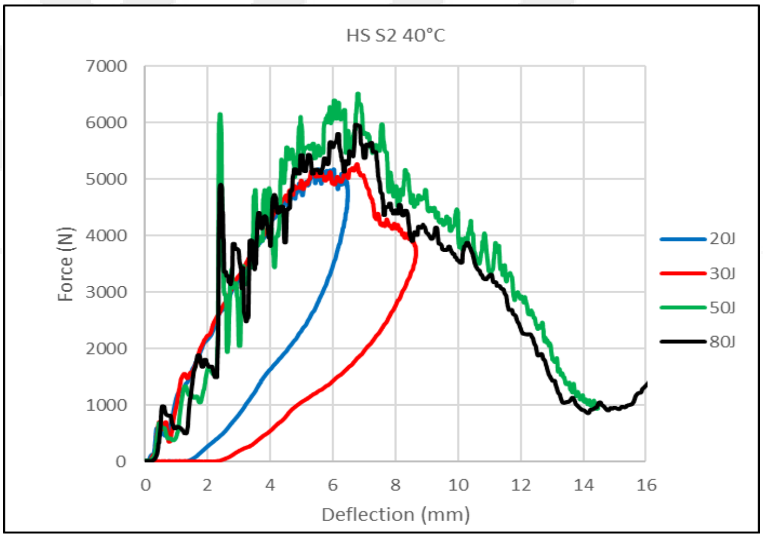


Figure 3.17 Force-deflection diagrams for S2 glass/epoxy hemispherical nose in impact test at 40°C

The results of force-deflection at 60 °C temperature are given in Figures 3.18 and 3.19. For the hybrid carbon-kevlar/epoxy specimen the rebounding occurs only at 20J, the penetration happened at 30J but a perforation is observed on 50J and 80J at impact energy specimen. The contact force increases when the impact energy increases. The result of S2 glass/epoxy specimen presented only perforation at 80J, the rebounding occurred at 20J, 30J and a penetration of the specimen is observed at 50J.

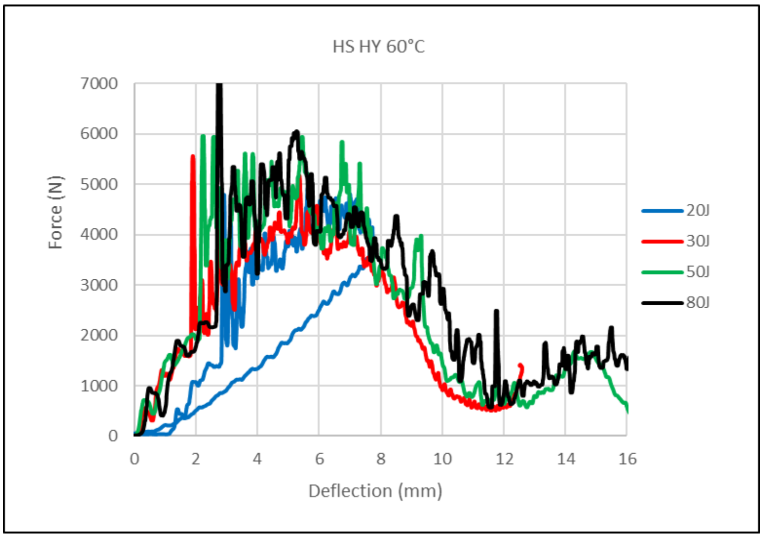


Figure 3.18 Force-deflection diagrams for hybrid carbon-kevlar/epoxy hemispherical nose in impact test at 60 °C

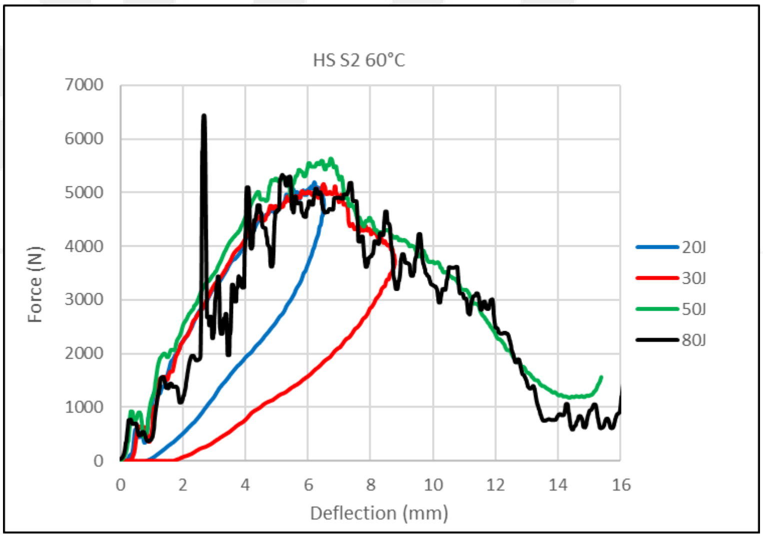


Figure 3.19 Force-deflection diagrams for S2 glass/epoxy hemispherical nose in impact test at 60 °C

The result of 80°C has been shown in Figures 3.20 and 3.21. The hybrid carbon-kevlar/epoxy specimen showed that rebounding occurs at the applied impact energy 20J followed by a penetration of the specimen at 30J and a perforation of the specimen at 50J and 80J. After penetration, contact force does not change significantly. Almost the same results were observed with S2 glass/epoxy specimen except the fact that rebounding occurs also at the applied impact energy 30J and a perforation of the specimen at 50J and 80J. After penetration, contact force does not change significantly.

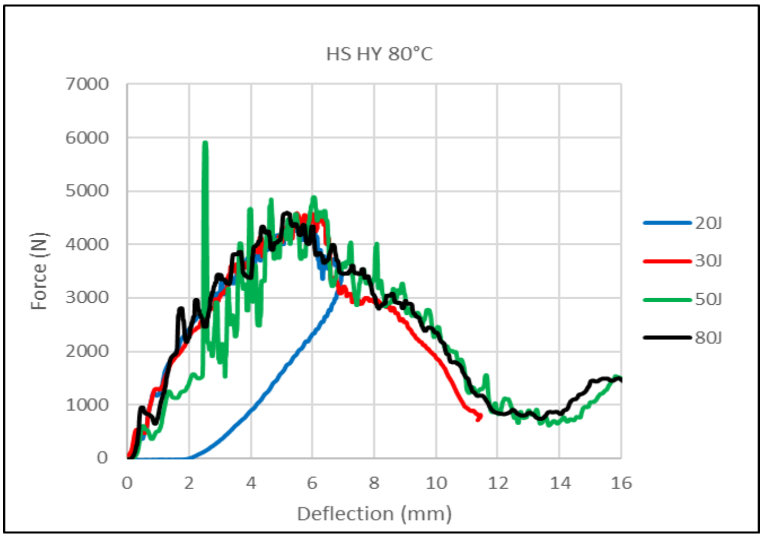


Figure 3.20 Force-deflection diagrams for hybrid carbon-kevlar/epoxy hemispherical nose in impact test at 80 °C

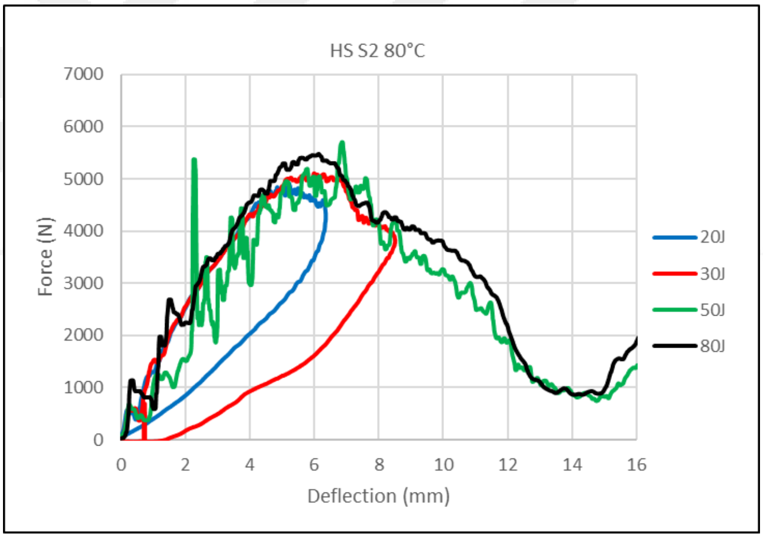


Figure 3. 21 Force-deflection diagrams for S2 glass/epoxy hemispherical nose in impact test at 80 °C

In Figure 3.22 which presents the temperature effects of a chosen impact energy 50J under the hemispherical nose punch it is noticed that all the specimens underwent perforation.

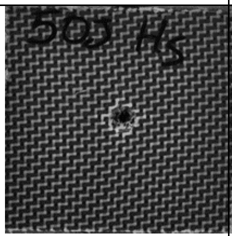
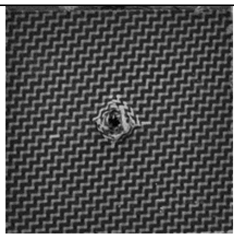
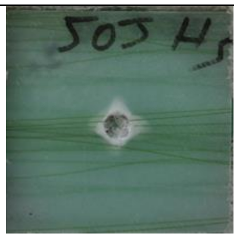
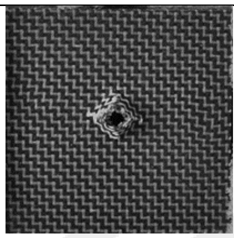
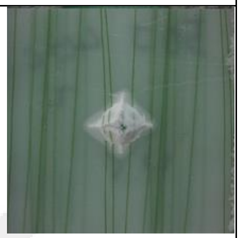
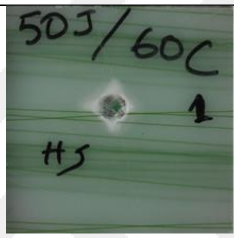
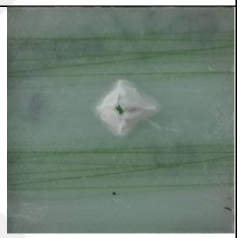
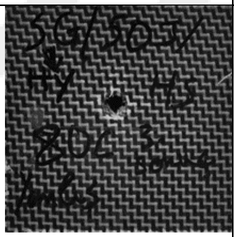
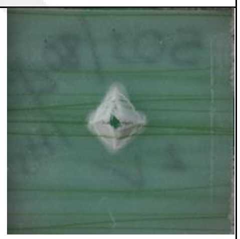
	50J HY		50J S2	
	Front face	Back face	Front face	Back face
23°C				
40°C				
60°C				
80°C				

Figure 3.22 Hemispherical nose LVI test specimens with 23ºC, 40ºC, 60ºC and 80ºC for 50J impact energy

Figure 3.23 presents the temperature effects of a chosen impact energy 80J under the hemispherical nose punch. Most of the mode failure occurred are delamination, and penetration

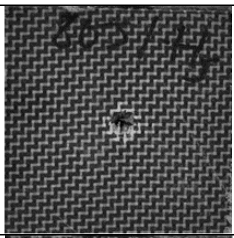
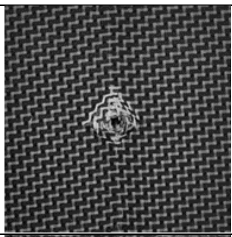
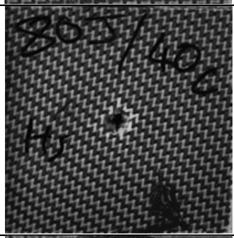
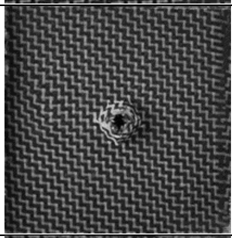
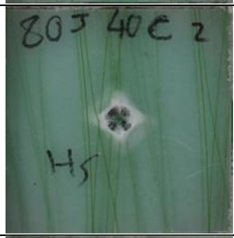
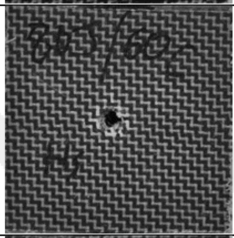
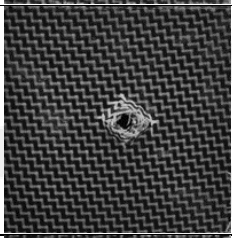
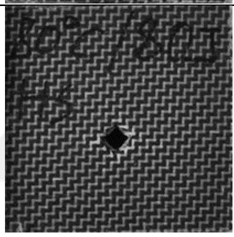
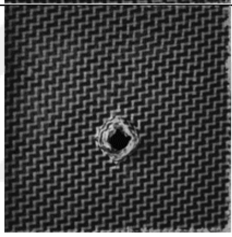
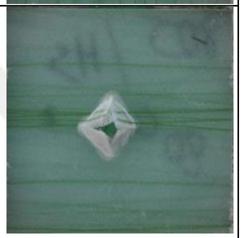
	80J HY		80J S2	
	Front face	Back face	Front face	Back face
23°C				
40°C				
60°C				
80°C				

Figure 3.23 Hemispherical nose LVI test specimens with 23ºC, 40ºC, 60ºC and 80ºC for 80J impact energy

3.2 Quasi-static test results (QST)

This section presents the results of quasi-static test on the specimen present in all the cases penetration and perforation. So, with the graphs as contact force versus deflection, impact energy and absorbed energy it was quite possible to understand the results.

3.2.1 QST results with flat nose (F) penetrator

Figures 3.24-3.25 showed with the flat nose that at room temperature 23°C all the specimens undergo perforation at all different velocities. The displacements occurred between 4 mm and 5.5 mm for hybrid specimen while it happened between 4.5 mm and 6 mm for the S2 glass specimen. The peak contact force happened with the S2 Glass/epoxy specimen at a rate of 40mm/min, but it is observed in hybrid carbon-kevlar/epoxy at the rate of 10mm/min. The lower contact force for the hybrid specimen is observed at rate of 40mm/min while the S2glass presents a lower contact force at rate of 10mm/min. After fiber rupture and plugging an earlier friction occurred at 1mm/rate with S2 glass/epoxy specimen. The S2 glass/epoxy specimen presented a bigger zone of elasticity.

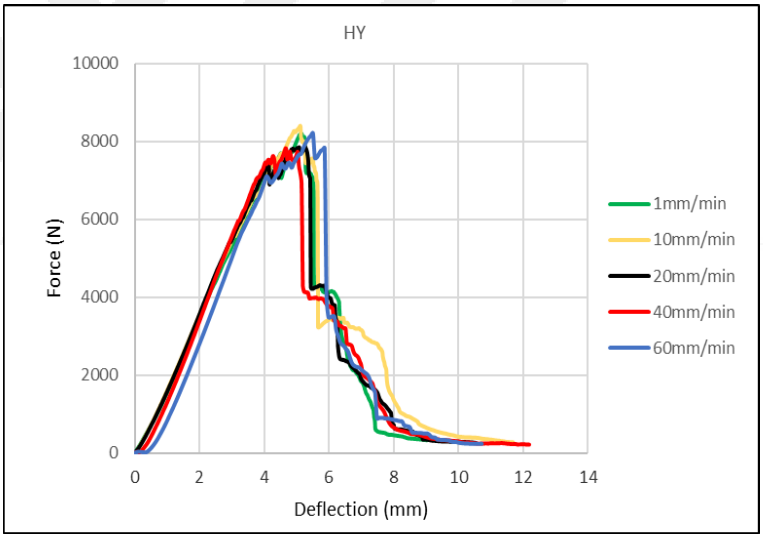


Figure 3.24 Force-deflection diagrams for hybrid carbon-kevlar/epoxy in quasi-static test at 23 ˚C

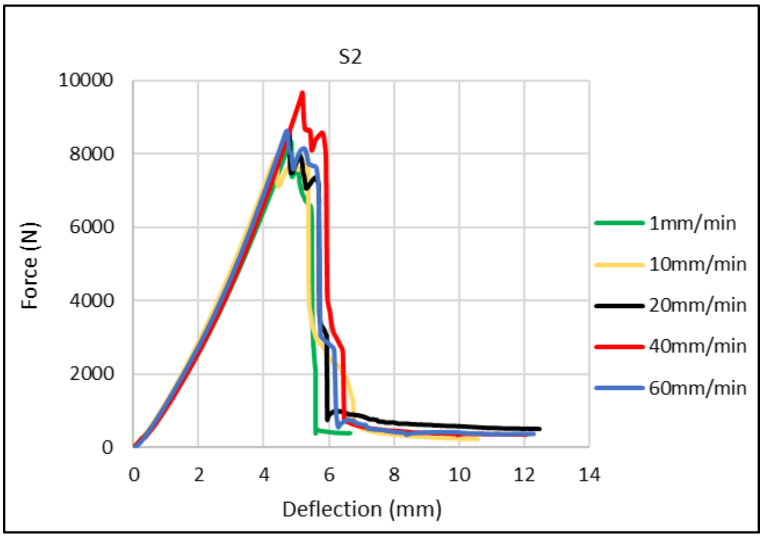


Figure 3.25 Force-deflection diagrams for S2 glass/epoxy in quasi-static test at 23 °C

With flat nose used Figure 3.26 present some tested specimen in quasi static test with all the velocities at room temperature. It is noticed that all the specimen undergone penetration and fiber breakage also occurred at all their rear sides.

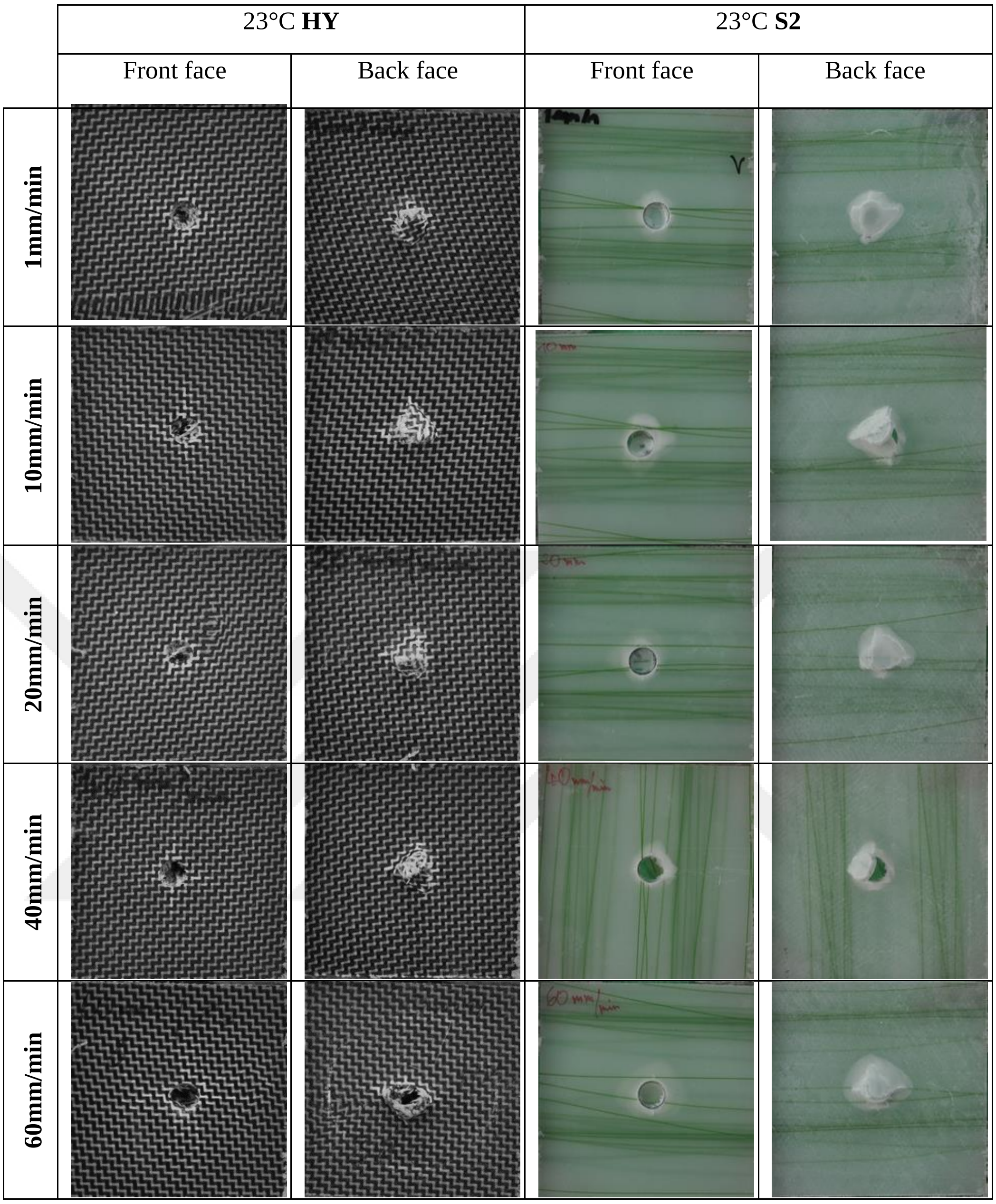


Figure 3.26 Flat nose QST test specimens with 1 mm/min., 10 mm/min., 20 mm/min, 40 mm/min and 60 mm/min for 23°C

From the graphs with flat nose results at temperature 40°C as presented in Figures 3.27-3.28, it can be seen that the perforation occurs in both specimens. However, S2 glass/epoxy specimen presents a greater zone of elasticity. The hybrid carbon-kevlar/epoxy specimen peak load is observed at 1mm/min velocity while the S2 glass/epoxy one is at 40mm/min. The displacements are concentrated between 4.5 mm and 5.5mm for S2 glass while the displacement in hybrid carbon-kevlar/epoxy specimen goes beyond the 6mm.The frictional forces are noticeable with the hybrid carbon-kevlar/epoxy specimen where the S2 glass/epoxy specimen underwent almost fully penetration of their specimen. The lowers contact forces are observed at 20mm/min and 10mm/min for hybrid carbon-kevlar/epoxy and S2 glass/epoxy specimen, respectively.

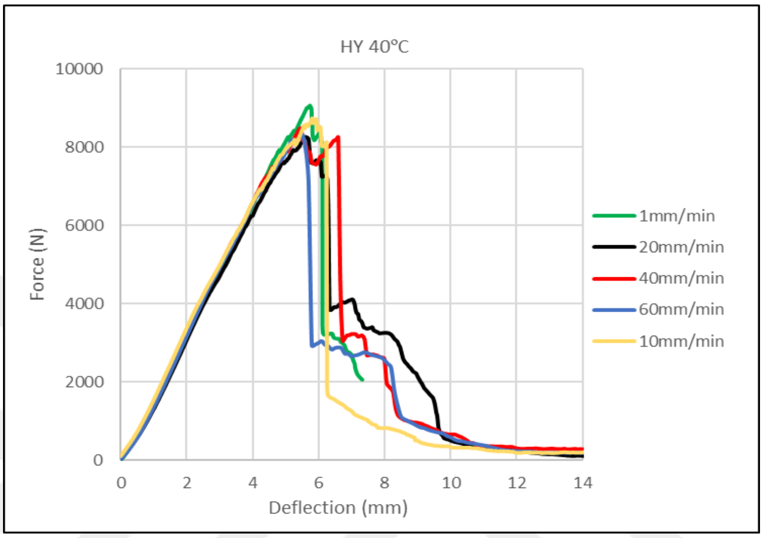


Figure 3.27 Force-deflection diagrams for hybrid carbon-kevlar/epoxy in quasi-static test at 40 °C

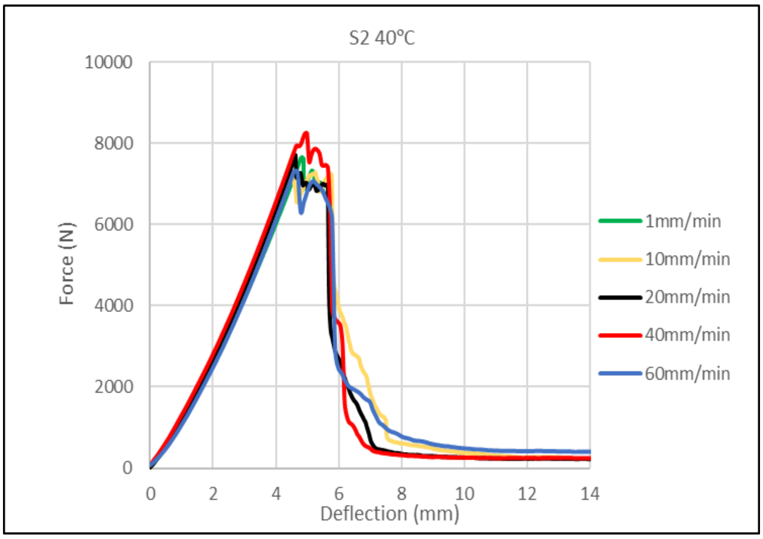


Figure 3.28 Force-deflection diagrams for S2 glass/epoxy in quasi-static test at 40 ° C

At temperature of 60°C the flat nose results graphs as shown in Figures 3.29 and 3.30, a peak contact force for hybrid carbon-kevlar/epoxy specimen while for S2 glass/epoxy specimen the peak force is observed at 40 mm/min. The displacements of hybrid carbon-kevlar/epoxy specimen is between 5mm and 8mm with a maximum displacement at 7 mm. In S2 glass/epoxy specimen case the displacements are concentrated between 3.25 mm and 3.5 mm. The lower contact forces are observed at 20 mm/min and 1mm/min for hybrid carbon-kevlar/epoxy and S2 glass/epoxy specimen respectively. The frictional forces are more noticeable with hybrid carbon-kevlar/epoxy specimen and it presents a greater zone of elasticity.

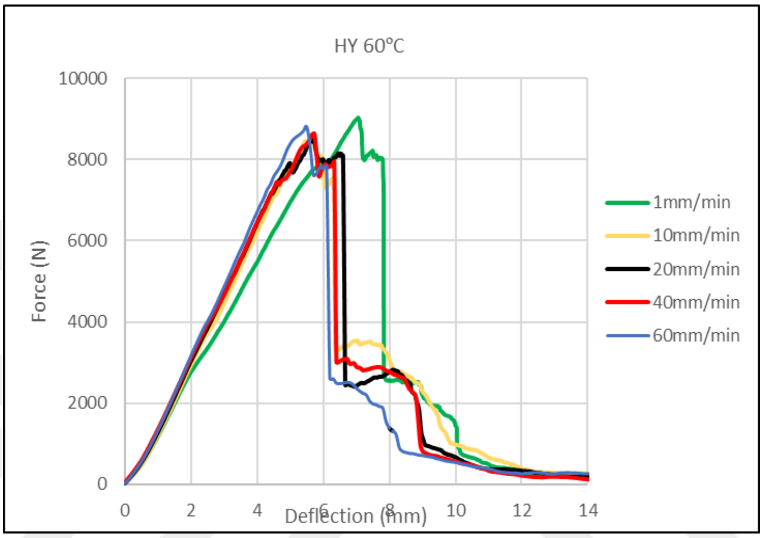


Figure 3.29 Force-deflection diagrams for hybrid carbon-kevlar/epoxy in quasi-static test at 60 °C

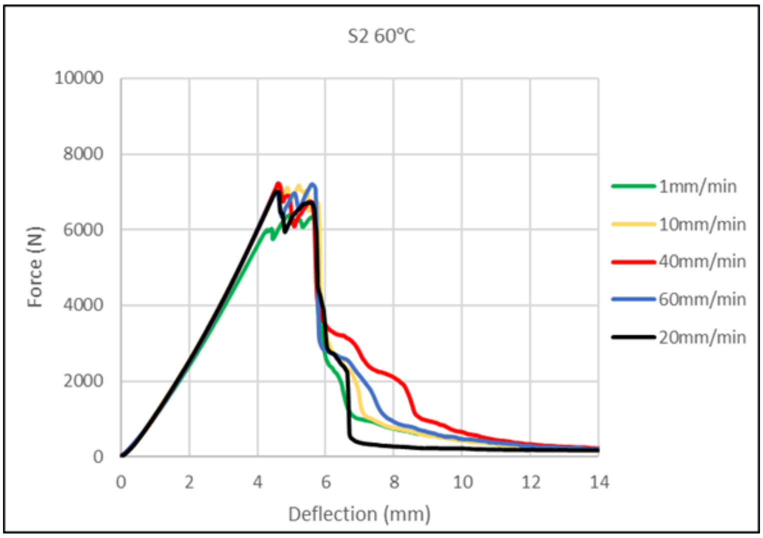


Figure 3.30 Force-deflection diagrams for S2 glass/epoxy in quasi-static test at 60 °C

Figure 3.31-3.32 present the flat nose graphs results at temperature of 80°C. It can be stated that, the most considerable peak contact force is observed from hybrid carbon-kevlar/epoxy specimen graph at rate of 1mm/min and the lowest peak load observed for S2 glass/epoxy specimen graph at rate of 1mm/min. The displacement value is situated between 5.25 mm and 10mm for hybrid carbon-kevlar/epoxy specimen with a maximal displacement of 9mm at 1mm/min whereas for S2 glass/epoxy specimen it is noticed that the displacements are concentrated between 4.5 mm and 6. 5 mm. In the hybrid carbon-kevlar/epoxy specimen graph, despite an early damage is noticed at 60 mm/min it can be said that it presents the greater zone of elasticity. The friction phenomena are more noticeable with the same specimen.

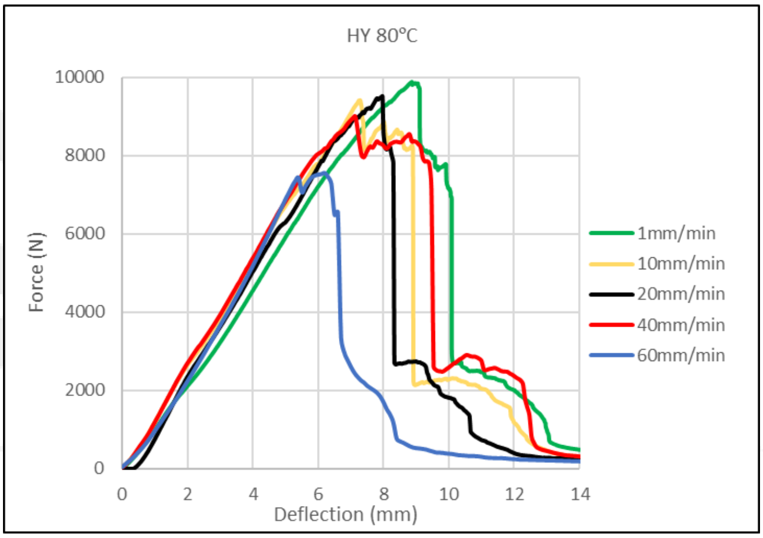


Figure 3.31 Force-deflection diagrams for hybrid carbon-kevlar/epoxy in quasi-static test at 80 °C

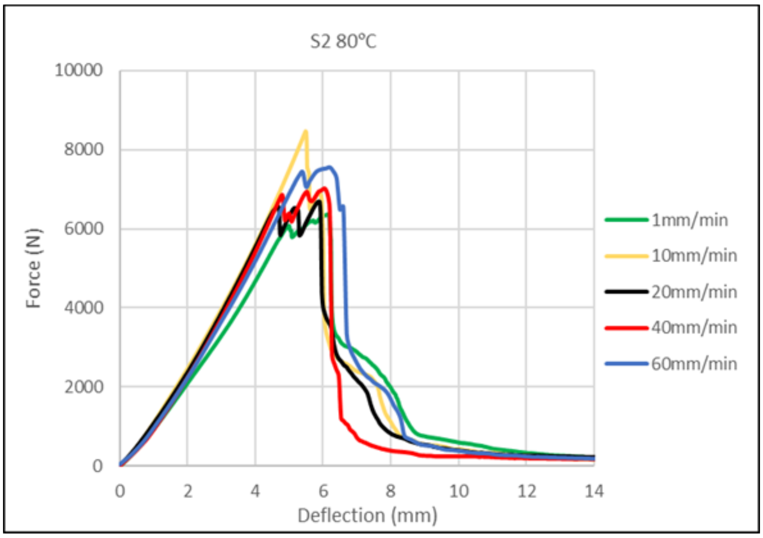


Figure 3.32 Force-deflection diagrams for S2 glass/epoxy in quasi-static test at 80 °C

With flat nose used Figure 3.33 presents some tested specimen in quasi static test at 60mm/min rate with all the temperatures. It is noticed that all the specimen undergone penetration and fiber breakage also occurred at all their rear sides.

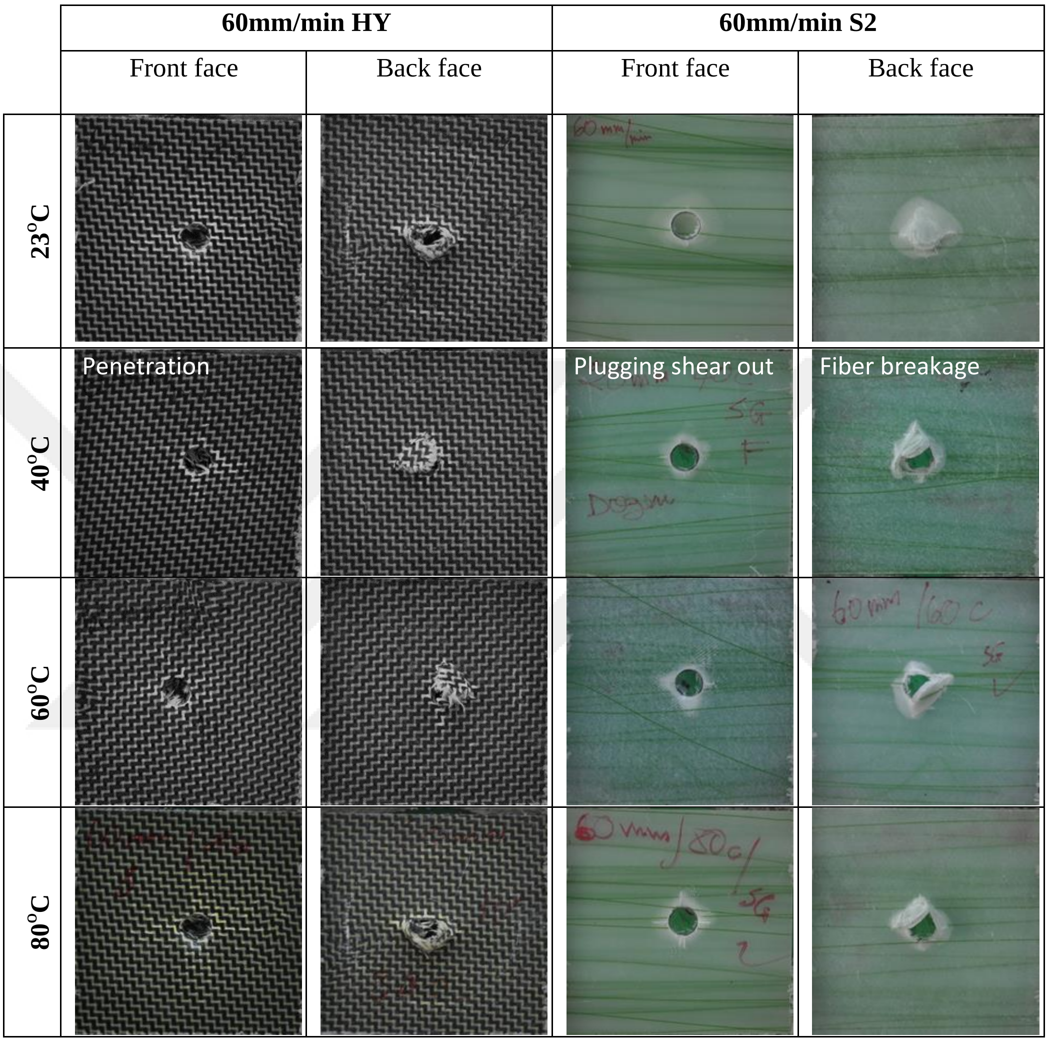


Figure 3.33 Flat nose QST test specimens with 60 mm/min for 23ºC, 40ºC, 60ºC and 80ºC

3.2.2 QST results with hemispherical nose (HS) penetrator

In overall graph results of the hemispherical nose penetrator it is observed that the entire specimen every parameter put together undergone perforation with a significant drop of force contact.

From the graphs of room temperature, 23ºC, (Figure 3.34), it is noticed a peak load at 10mm/min of hybrid carbon-kevlar/epoxy specimen, which value is higher than the S2 glass/epoxy specimen at the same rate in Figure 3.35. The displacements rate is concentrated between 4 mm and 5.5 mm of hybrid carbon-kevlar/epoxy specimens with a maximal displacement observed at 10mm/min while the displacements of S2 glass/epoxy specimen are located between 4mm and 10mm with a maximal displacement at 10 mm/min. The damaged zone of S2 glass/epoxy specimens is greater than hybrid carbon-kevlar/epoxy specimens one. Moreover, a sudden drop of force is notice just after a complete formation of plug.

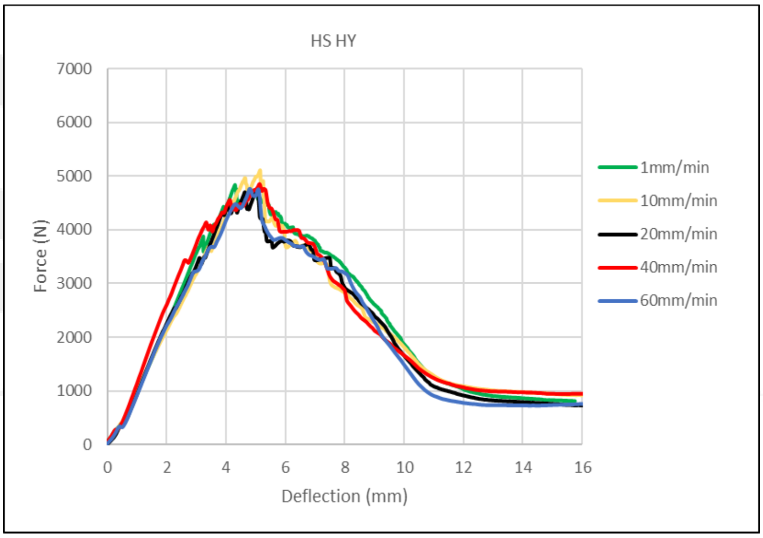


Figure 3.34 Force-deflection diagrams for hybrid carbon-kevlar/epoxy hemispherical nose in quasi-static test at 23 ºC

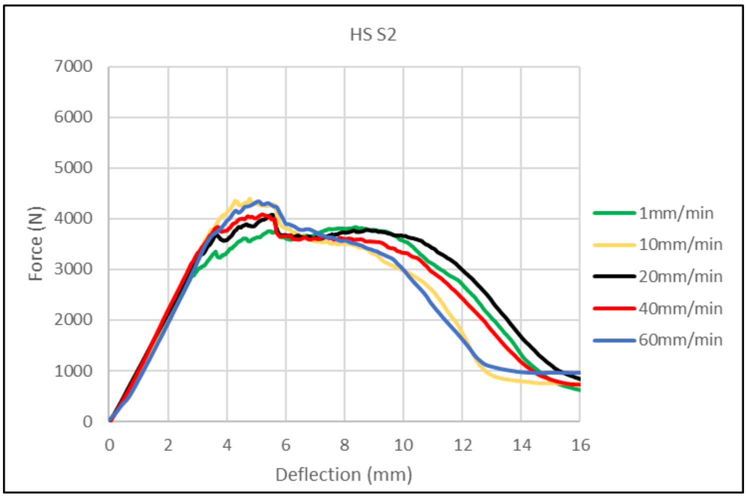


Figure 3.35 Force-deflection diagrams for S2 glass/epoxy hemispherical nose in quasi-static test at 23°C

Figure 3.36 presents some specimens tested with the hemispherical nose.at room temperature under the all different all the velocities in quasi-static test. It can be observed that all the specimens underwent penetration.

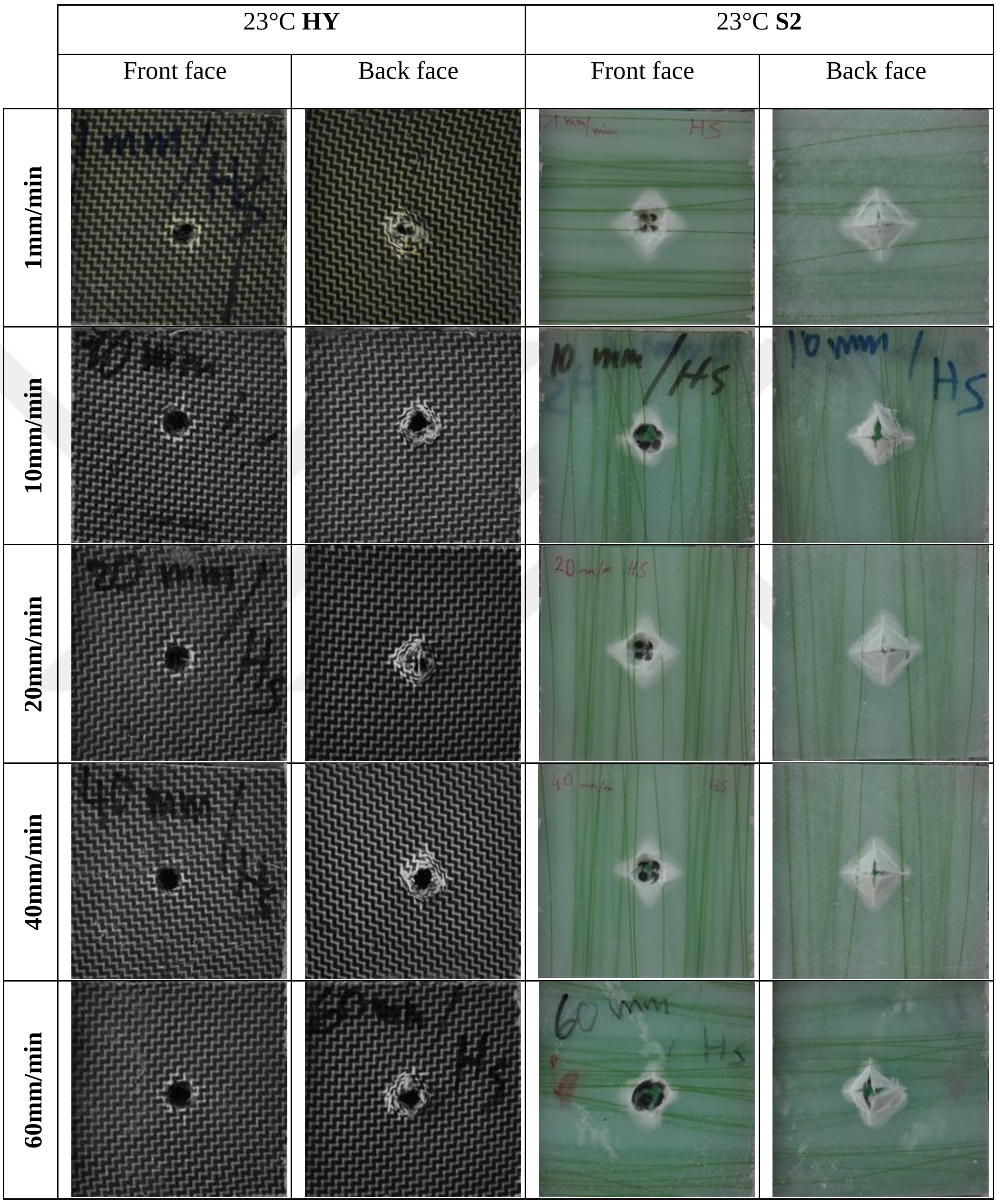


Figure 3.36 Hemispherical nose LVI test specimens with 20J, 30J, 50J and 80J impact energy for 23°C

After the graphs results at temperature 40°C of the two different specimens from Figures 3.37-3.38 can be observed the peak load is detected at 10 mm/min and 60 mm/min of hybrid carbon-kevlar/epoxy and S2 glass/epoxy specimen respectively. A greater elastic zone is observed with hybrid carbon-kevlar/epoxy specimens but also a considerable tensile value of the remaining composite is observed after complete formation of the plug. For S2 glass/epoxy specimen the friction zone lasted more after the plugging and fiber rupture. The lower contact force for both has been observed at rate of 1mm/min.

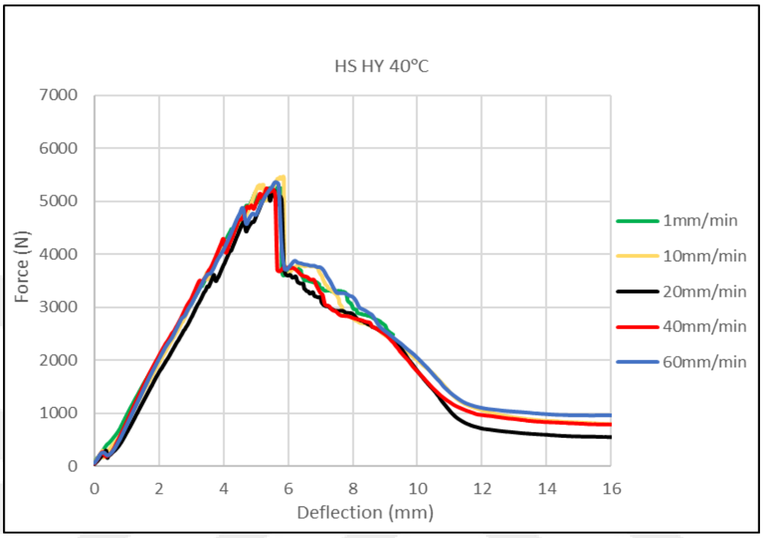


Figure 3.37 Force-deflection diagrams for hybrid carbon-kevlar/epoxy hemispherical nose in quasi-static test at 40 °C

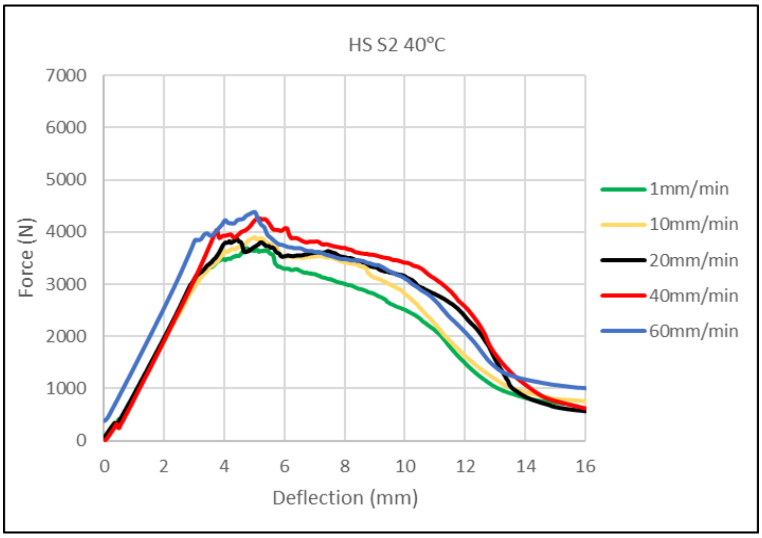


Figure 3.38 Force-deflection diagrams for S2 glass/epoxy hemispherical nose in quasi-static test at 23°C

Figures 3.39 and 3.40 showed the graphs result at temperature 60°C. The penetration force increases linearly up to matrix cracking. The highest load is observed at rate of 1 mm/min and 60 mm/min respectively for hybrid carbon-kevlar/epoxy and S2 glass/epoxy specimen. A sudden drop of the load is noticed in hybrid carbon-kevlar/epoxy specimen followed by a considerable force friction. Its displacements are varied in a concentrated manner between 5 mm and 6.5 mm. As for glass/epoxy specimens, they have their displacement rate between 3 mm and 8 mm followed by a less abrupt drop of load after the critical fiber rupture followed itself by a considerable friction force area.

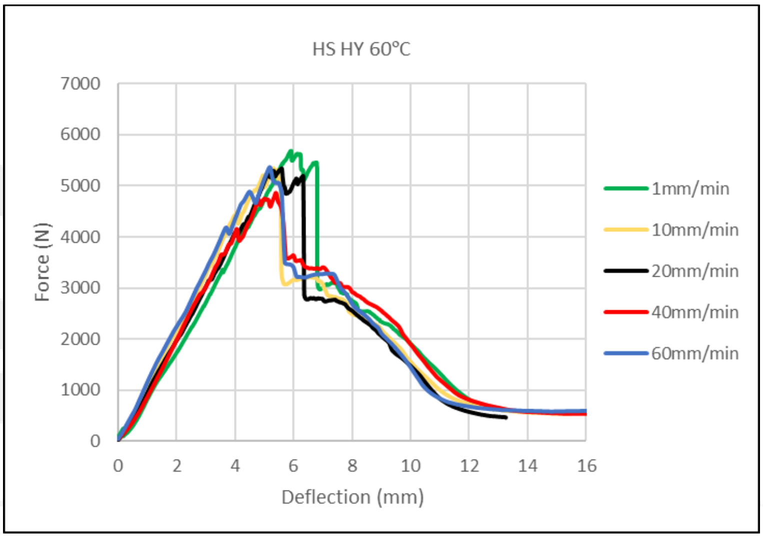


Figure 3.39 Force-deflection diagrams for hybrid carbon-kevlar/epoxy hemispherical nose in quasi-static test at 60 °C

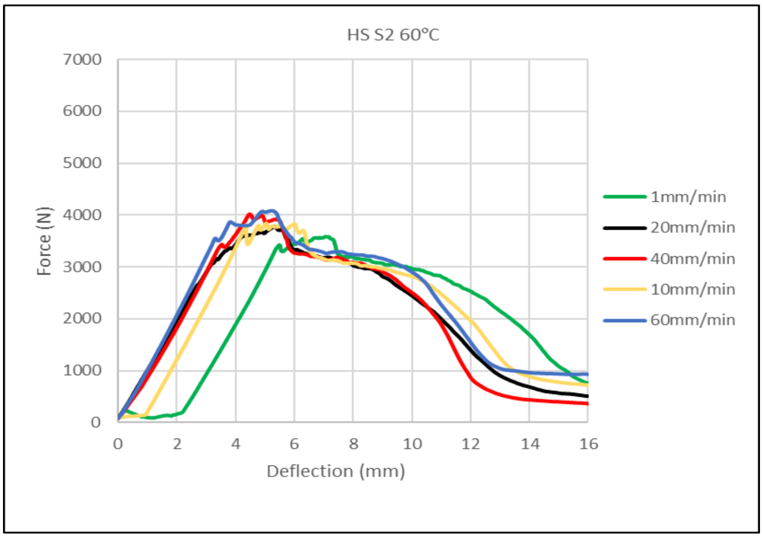


Figure 3.40.Force-deflection diagrams for S2 glass/epoxy hemispherical nose in quasi-static test at 60 °C

Figures 3.41-3.42 shows the graphs result of both specimens at temperature of 80ºC. It can be observed a linear increase of penetration forces up to the matrix cracking for both specimens. In case of hybrid carbon-kevlar/epoxy specimen the peak load is reached at rate of 1 mm/min, the sudden drop of load is observed in all velocities and non-considerable friction force effect except at rate of 60 mm/min. The displacements are situated between 5 mm and 8.75 mm. With the S2 glass/epoxy specimen, the peak load is reached at the 1 mm/min velocity and a concentration of displacement value between 4 mm and 6 mm. The specimens after their peak load are followed generally this time by a progressive drop of load occurring more displacement and the composites lost their strength and breaks under the tension shear force.

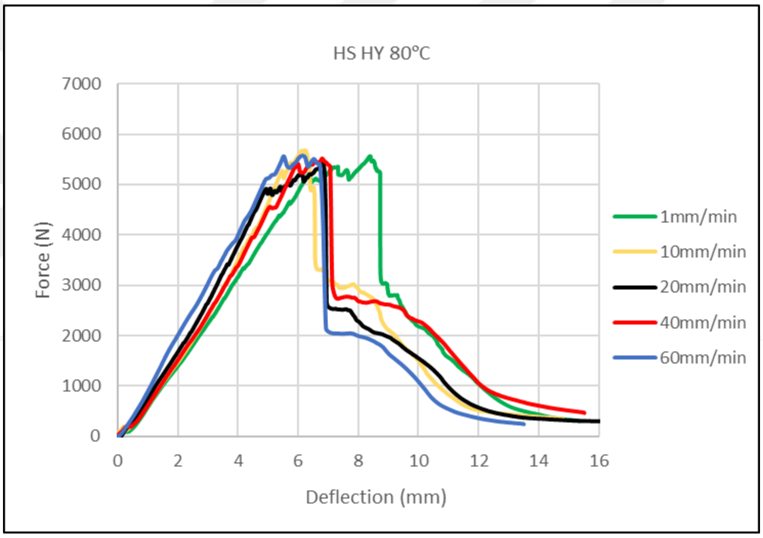


Figure 3.41 Force-deflection diagrams for hybrid carbon-kevlar/epoxy hemispherical nose in quasi-static test at 80 °C

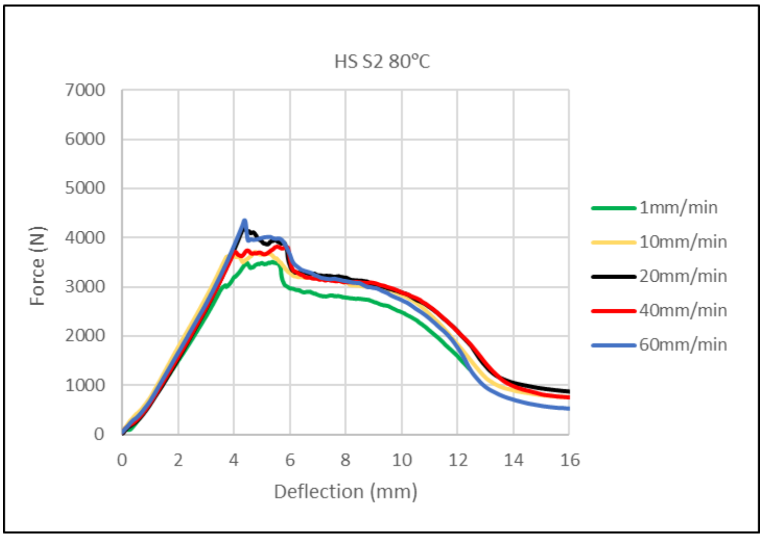


Figure 3.42 Force-deflection diagrams for S2 glass/epoxy hemispherical nose in quasi-static test at 80 °C

With hemispherical nose used Figure 3.43 present some tested specimen in quasi static test at 40mm/min rate with all the temperatures. It is noticed that all the specimen undergone penetration and fiber breakage also occurred at all their rear sides.

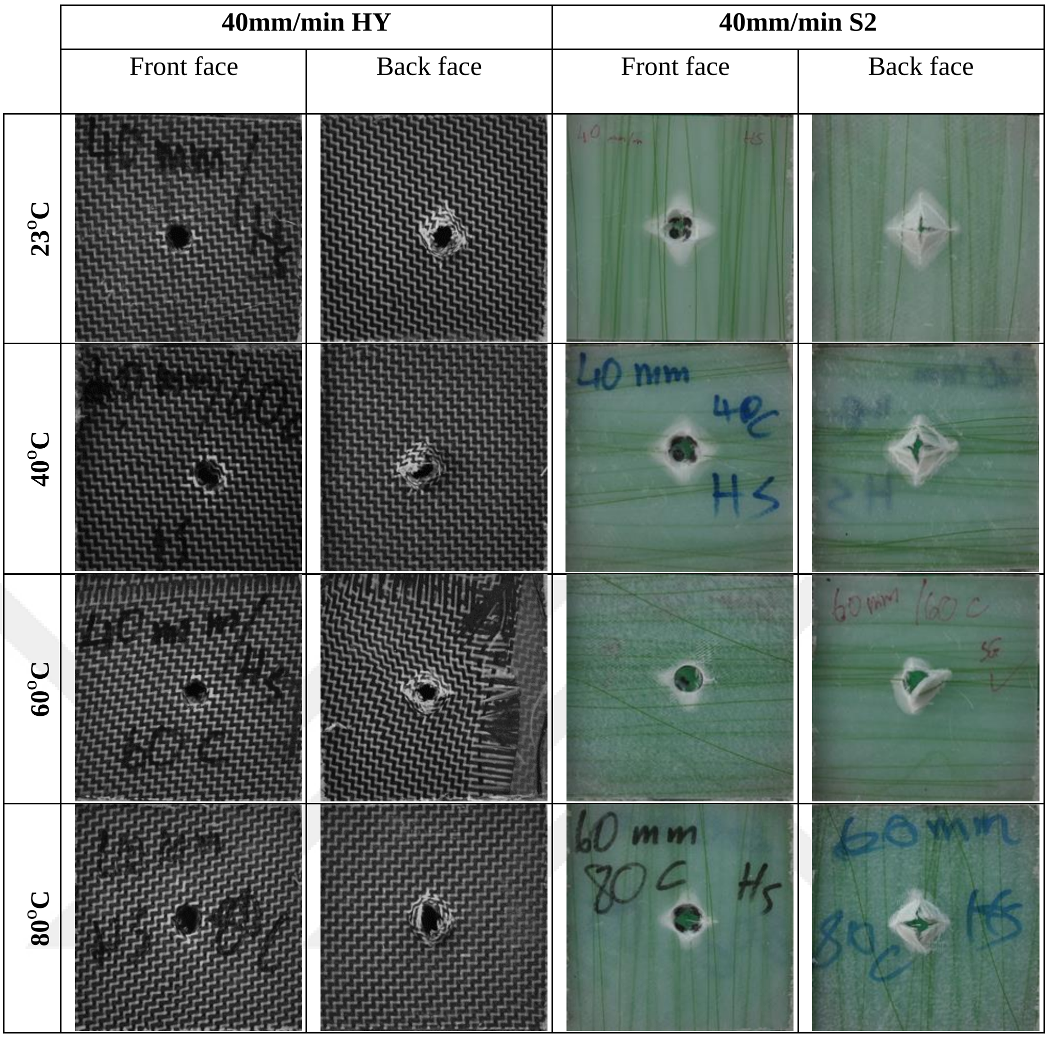


Figure 3.43 Hemispherical nose QST test specimens with 40 mm/min for 23ºC, 40ºC, 60ºC and 80ºC temperature

3.3 Comparison of absorbed energy of same composite specimen under two different tests

The absorbed energy versus impact energy and test speed diagrams are given in Figures 3.44-3.45 for the hybrid and glass reinforced composites at room temperature 23°C. With flat nose case, the hybrid specimen presented almost a same result in the two different tests while the S2 glass specimen’s results are quite different. At low velocity test a sudden increase is obtained at 30J but in quasi-static test an almost constancy of absorbed energy has been observed. In hemispherical nose case it can be seen an increase of absorbed energy in proportion to the increase the impact energy and velocity. Moreover, a sharp increase of absorbed energy of fiber reinforced composite at 50J impact energy applied.

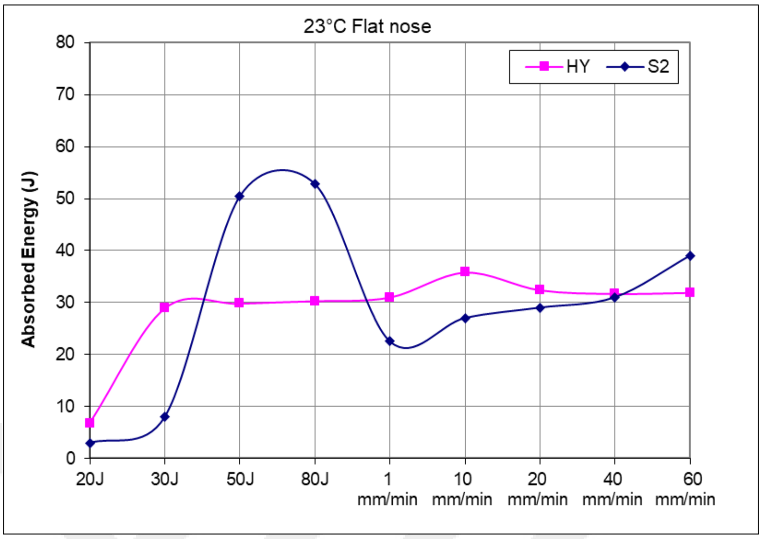


Figure 3.44 Absorbed energy of S2 glass/epoxy and Hybrid carbon-kevlar/epoxy composites for LVI and QST tests by using flat nose at 23°C

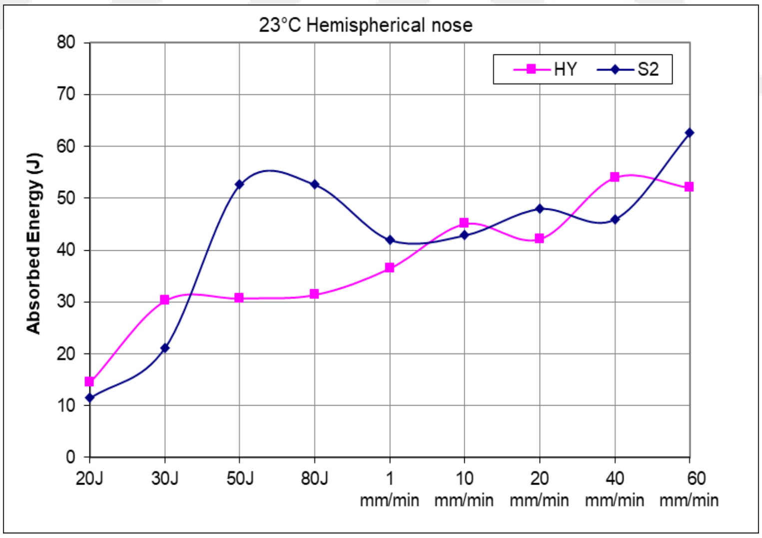


Figure 3.45 Absorbed energy of S2 glass/epoxy and Hybrid carbon-kevlar/epoxy composites for LVI and QST tests by using hemispherical nose at 23 °C

From the graphs obtained in Figures 3.46 and 3.47 at 40°C temperature under the flat tip the S2 glass/epoxy specimen absorbed energy increase rapidly after the 30J impact energy but underwent a drop at the 20mm/min velocity. The peak-absorbed energy has been observed at 80J impact energy. A contrasted reaction is observed over the two different. With the hybrid carbon-kevlar/epoxy specimen it is noticed an almost constancy over the two different experiment with a little bit increase of absorbed energy at 60 mm/min velocity for HS impactor. Under the hemispherical tip, it can be observed that the more the velocity increase the more is the increase of absorbed energy in both specimens. The S2 glass/epoxy specimen got the highest absorbed energy. The steadiness of absorbed energy is observed also in low velocity impact of hybrid carbon-kevlar/epoxy specimen where it is not the case under the S2 glass/epoxy specimen.

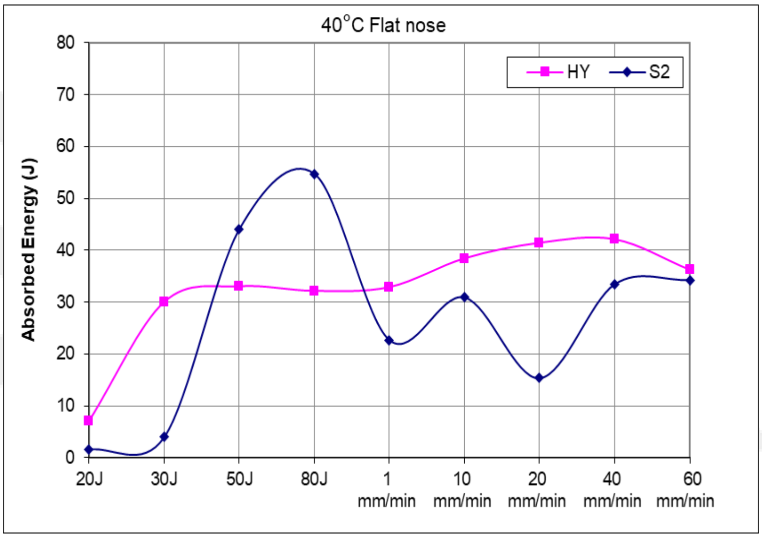


Figure 3.46 Absorbed energy of S2 glass/epoxy and Hybrid carbon-kevlar/epoxy composites for LVI and QST tests by using flat nose at 40°C

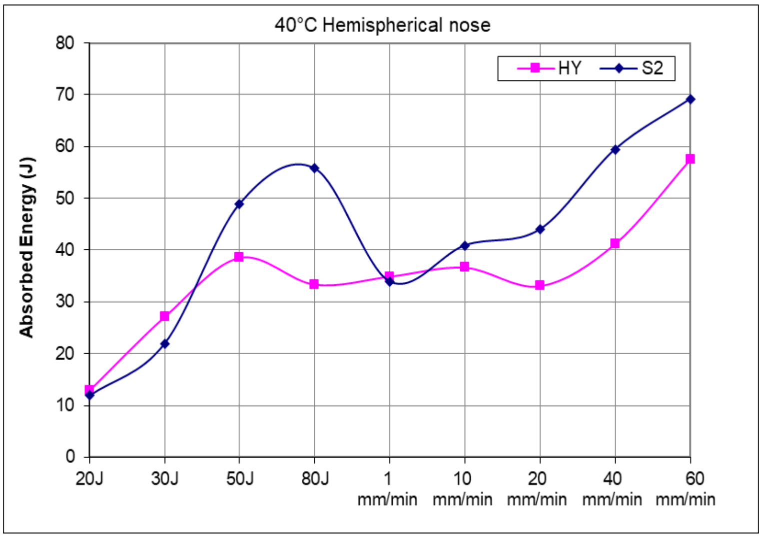


Figure 3.47 Absorbed energy of S2 glass/epoxy and Hybrid carbon-kevlar/epoxy composites for LVI and QST tests by using hemispherical nose at 40 °C

Figures 3.48-3.49 presents the results of absorbed energy at 60°C temperature allowed saying that under the flat tip case with S2 glass/epoxy specimen the value of absorbed energy increase abruptly after the 30J impact energy but it stays constant in quasi-static test. Meanwhile, with the hybrid carbon-kevlar/epoxy specimen a linear increase has been observed at the start of low velocity impact whereas a slight decrease has been observed at the beginning of quasi-static test. Under the hemispherical tip case the behavior of the absorbed energy of both specimens remained constant in quasi-static test and the same phenomena has been observed except for the little high amount of the absorbed at 80J impact energy of S2 glass/epoxy specimen.

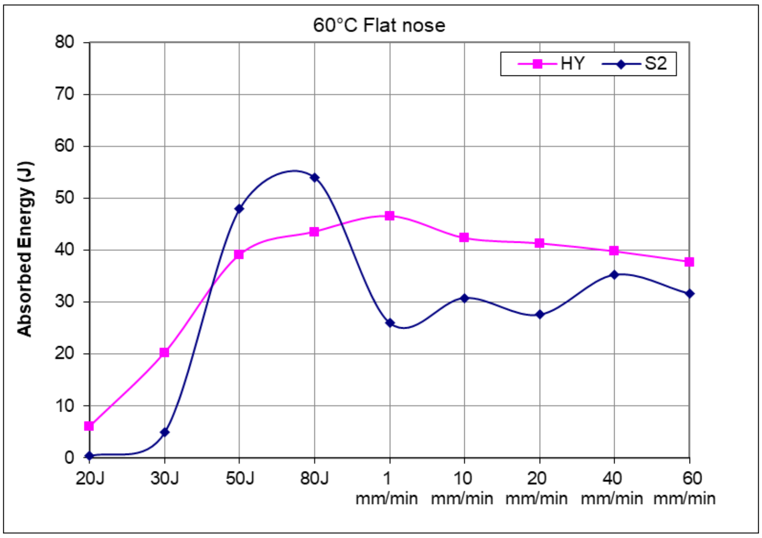


Figure 3.48 Absorbed energy of S2 glass/epoxy and Hybrid carbon-kevlar/epoxy composites for LVI and QST tests by using flat nose at 60°C

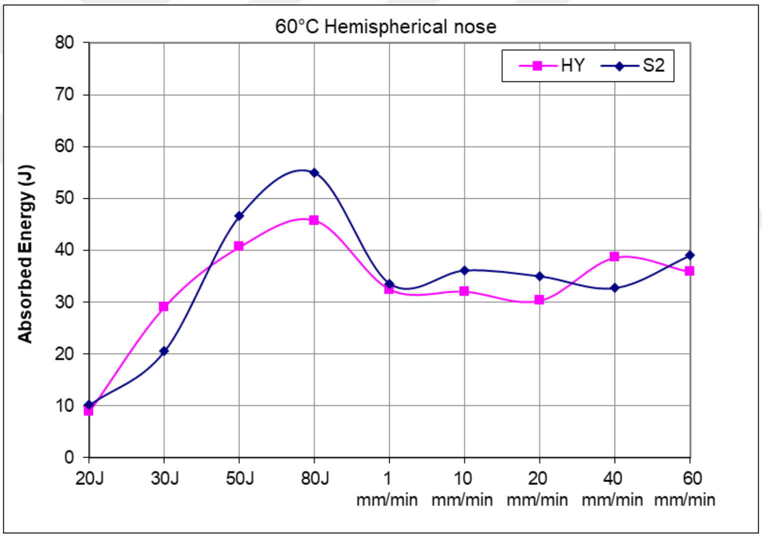


Figure 3.49 Absorbed energy of S2 glass/epoxy and Hybrid carbon-kevlar/epoxy composites for LVI and QST tests by using hemispherical nose e at 60°C

At temperature of 80ºC the results graph of compared absorbed energy as presented in Figures 3.50-3.51 indicate that the behavior of the S2 glass/epoxy specimen have been almost the same all parameter put together. A constancy of the absorbed energy in quasi-static and a sharp increase of absorbed energy after 30J impact in low velocity impact test are observed. Meanwhile the hybrid carbon-kevlar/epoxy specimen presents a total disparity of its results. A linear increase of absorbed energy is observed under the flat tip case and more increase noticed in quasi-static test with a sinusoidal trend of the graph. The same specimen under hemispherical tip case showed a constancy of over the two different tests.

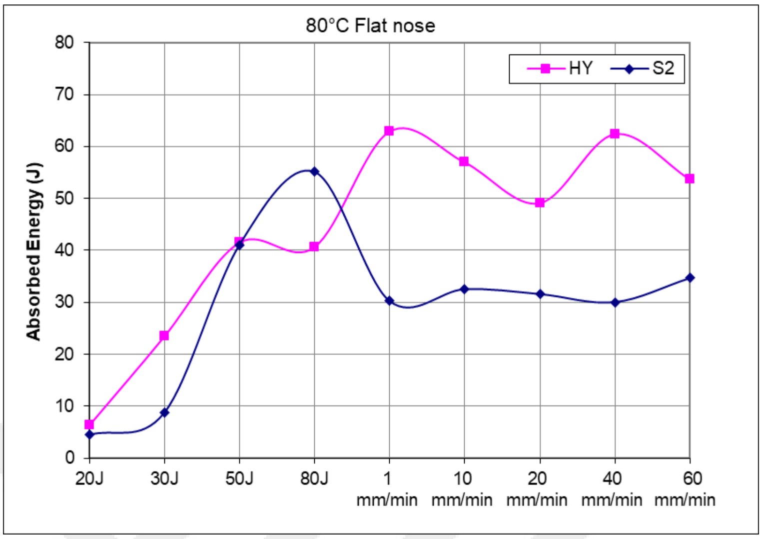


Figure 3.50 Absorbed energy of S2 glass/epoxy and Hybrid carbon-kevlar/epoxy composites for LVI and QST tests by using flat nose at 80 °C

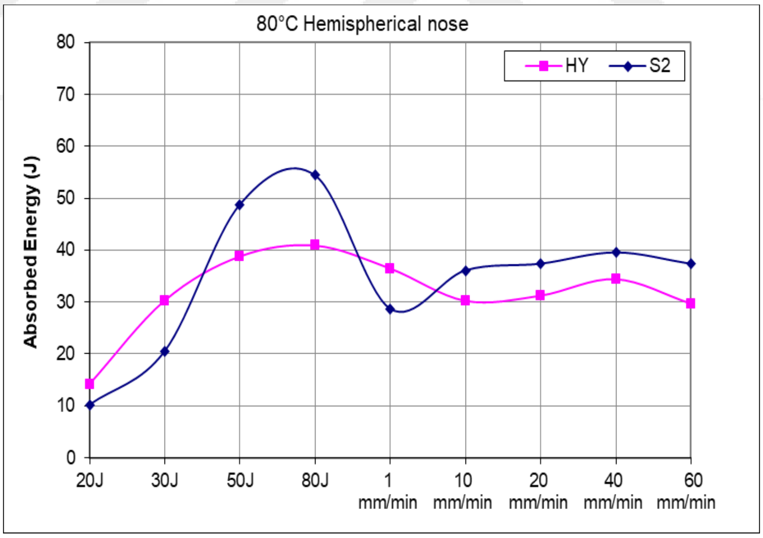
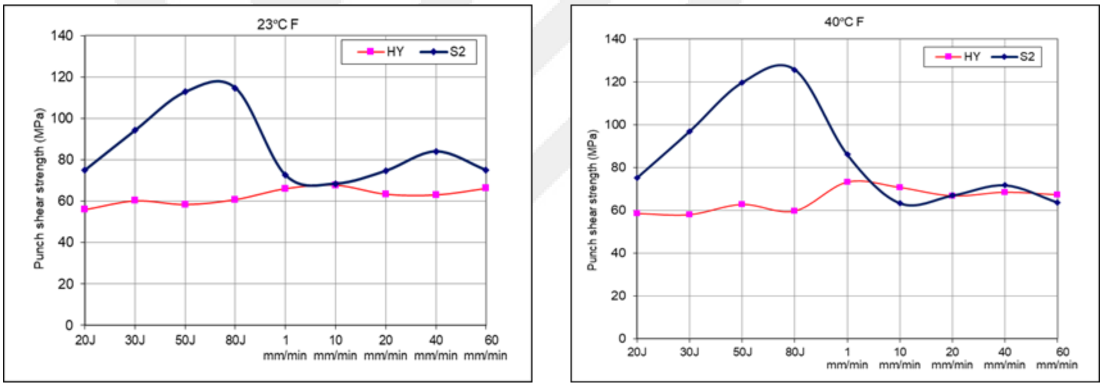


Figure 3.51 Absorbed energy of S2 glass/epoxy and Hybrid carbon-kevlar/epoxy composites for LVI and QST tests by using hemispherical nose at 80 °C

3.4 Punch shear strength

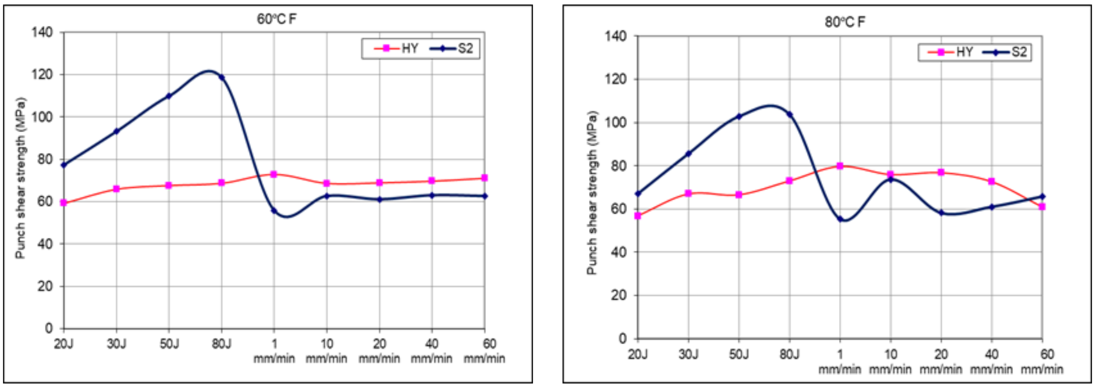
Figure 3.52 illustrates the diagram values of shear stress in case of flat penetrators used with both specimens in the two different tests at room temperature and 40ºC. It can be observed that the shear stress values of hybrid carbon-kevlar/epoxy specimen is constant in both tests of two temperature condition. In low velocity test of two temperature conditions of S2 glass/epoxy specimen the more the impact energy increases the more the punch shear strength value does. But at 23ºC the S2 glass/epoxy specimen present two different results and shows higher values of shear strength specially in low velocity test where the highest value is reached at 80J impact energy. For 40ºC case in quasi-static test presents the same behavior of both specimens have been observed.



a) b)

Figure 3.52 Punch shear strength of S2 glass/epoxy and hybrid carbon-kevlar/epoxy composite for LVI and QST tests under flat nose (a) at 23 °C (b) at 40 °C

Figure 3.53 shows the diagram values of the punch shear strength in case of flat penetrators used with both specimens in the two different tests at 60ºC and 80ºC. The graphs present almost the same behavior. The hybrid carbon-kevlar/epoxy specimen presented a constancy of results over the two different tests. In low velocity test the increase of the impact energy of S2 glass/epoxy specimen implies the increase of the punch shear strength value. With the quasi-static test, the S2 glass/epoxy specimen graph shows a constancy of its behavior but their values are lower than the hybrid carbon-kevlar/epoxy specimen ones at 60ºC. The lowest punch shear strength is observed at 1mm/min rate. Specially in case of 80ºC with the quasi-static test case an uneven behavior of the S2 glass/epoxy specimen is observed.



a) b)

Figure 3.53 Punch shear strength of S2 glass/epoxy and hybrid carbon-kevlar/epoxy composite for LVI and QST tests under flat nose (a) at 60 °C (b) at 80 °C

3.5 Absorbed energy and impact energy/QST velocity

Figures 3.54-3.55 represent the energy profile diagram of both specimens under the flat tip intender. From hybrid carbon-kevlar/epoxy specimen, it can be seen that the rebounding starts from the 20J impact energy and a perforation is observed at 30J absorbed energy with the lowest temperature at 23º C and 40º C. In addition, just after a perforation the absorbed energy is constant. As for the 60 º C and 80º C temperature, the absorbed energy increases up to 40J absorbed energy without occurring of perforation and remains nearly constant. From the S2 glass/epoxy specimen it is noticed that rebounding starts at 20J impact energy the increase occurs considerably until 50J where the perforation occurs with 60º C and 23º C. However, no perforation has been observed at 40ºC and 80ºC.

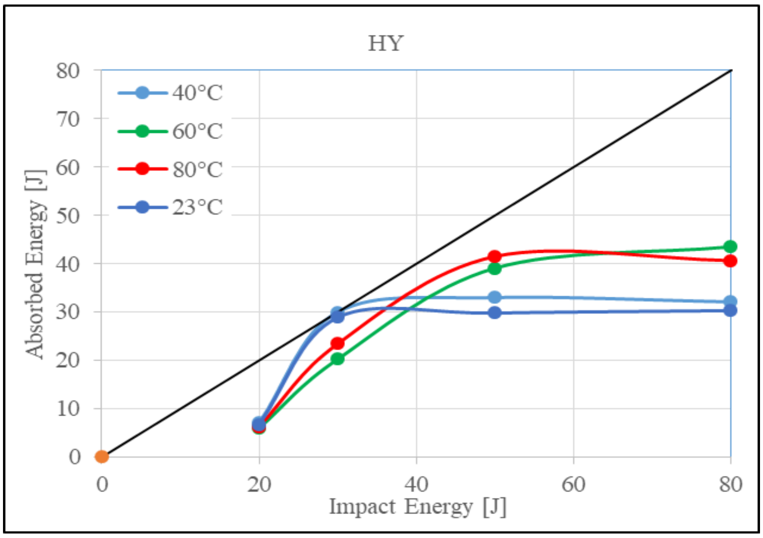


Figure 3.54 Absorbed energy-impact energy diagram under low velocity impact with flat nose penetrator for hybrid carbon-kevlar/epoxy composite

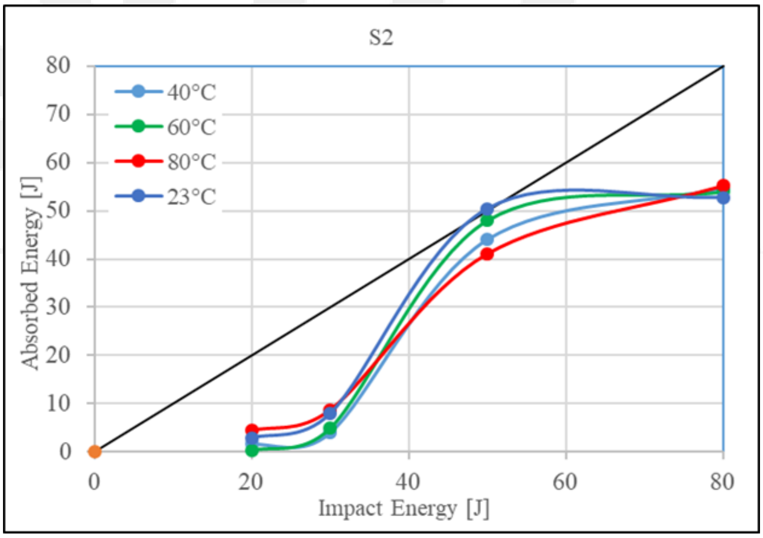


Figure 3.55 Absorbed energy-impact energy diagram under low velocity impact with flat nose penetrator for S2 glass/epoxy composite

Figures 3.56-3.57 show the graph result of the energy profile diagram of the specimens with hemispherical tip penetrator. From the hybrid carbon-kevlar/epoxy specimen, it is observed that the rebounding starts at 20J impact energy and at 30J absorbed energy perforation occurred at almost all the temperatures. The absorbed energy is nearly constant after the perforation at all temperatures. From S2 glass/epoxy specimen, similar behavior of the specimen at all temperature is noticed, which is expressed by a rebounding started at 20J impact energy followed by a serious increase of absorbed energy at 50J where the penetration occurred.

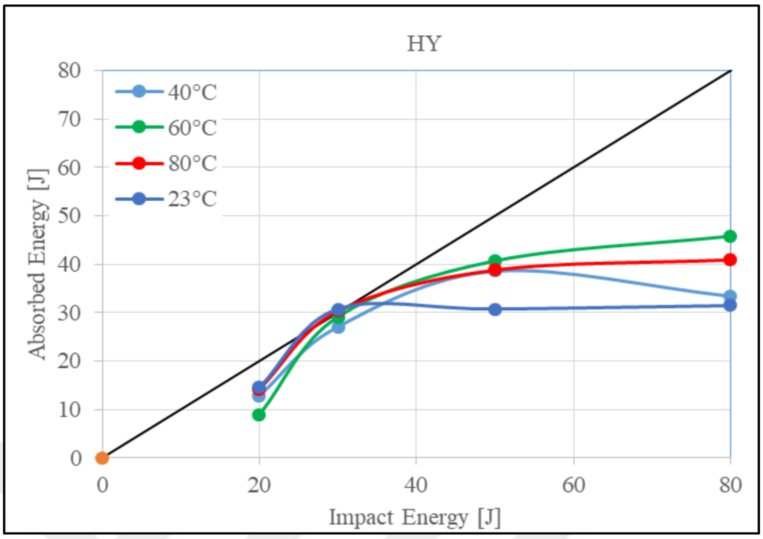


Figure 3.56 Absorbed energy-impact energy diagram under low velocity impact with hemispherical nose penetrator for hybrid carbon-kevlar/epoxy composite

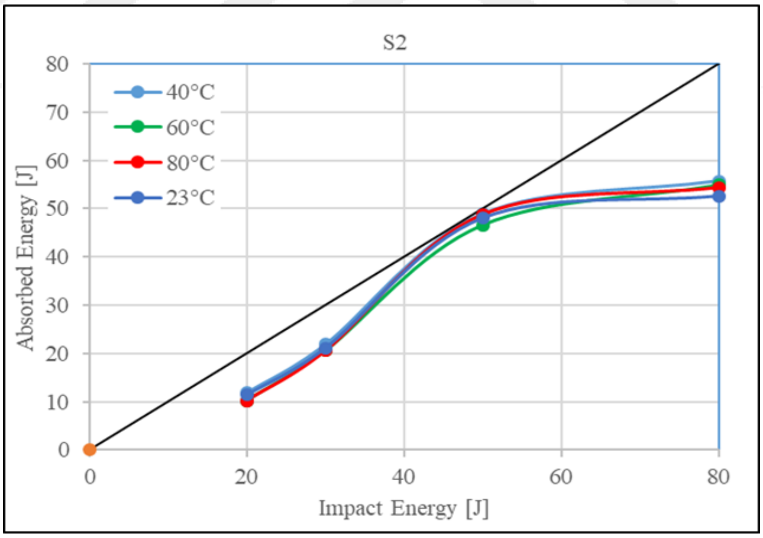


Figure 3.57 Absorbed energy-impact energy diagram under low velocity impact with hemispherical nose penetrator for S2 glass/epoxy composite

Figures 3.58-3.59 presents the results graph of absorbed energy and impact energy as observed during the quasi-static test with flat tip intender of the two different specimens. Under the hybrid carbon-kevlar/epoxy composite it can be seen that all the specimens undergone perforation, at 80 ºC temperature the higher absorbed energies are noticed, and the lowest at 23º C temperature. At 60º C and 80º C, the absorbed energy result present almost the same result after the 10mm/min velocity. Under the S2 glass/epoxy specimen the value of absorbed energy dropped and almost a same behavior of the curve is noticed for all the velocities except that at 20mm/min the absorbed energy dropped considerably at 20 mm/min.

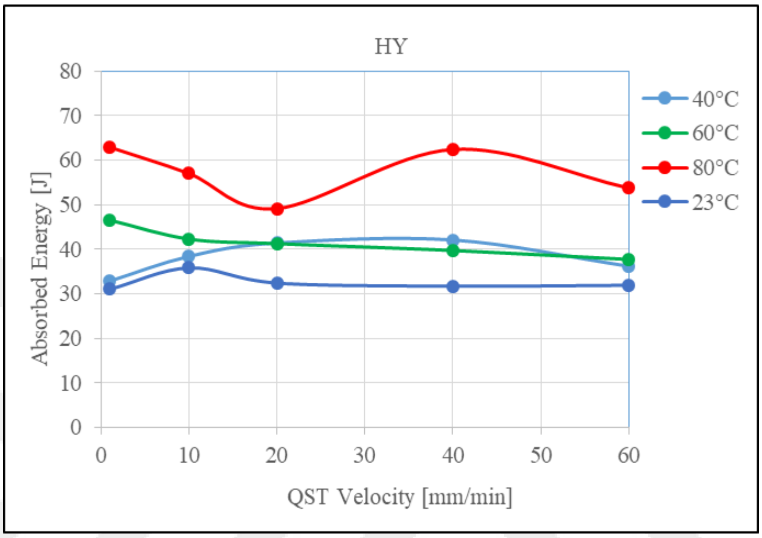


Figure 3.58 Absorbed energy versus QST velocity diagram under quasi-static test with flat nose penetrator for hybrid carbon-kevlar/epoxy composite

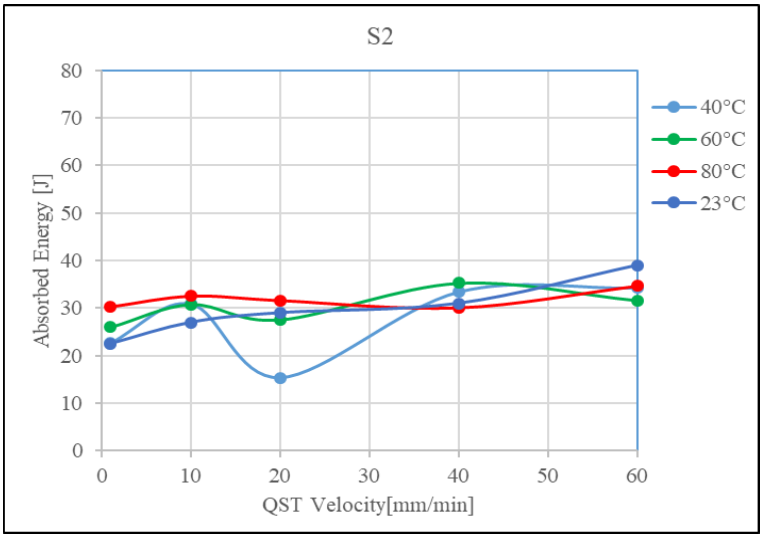


Figure 3.59 Absorbed energy versus QST velocity diagram under quasi-static test with flat nose penetrator S2 glass/epoxy composite

Figures 3.60-3.61 represent the result graph of absorbed energy and impact energy diagram under quasi-static test with hemispherical tip intender of the two different specimens. From the rate of 1mm/min to 60mm/min, it is noticed a small increase of the absorbed energy at 23ºC and 40ºC curve temperature but the graph at 60ºC and 80ºC temperatures present almost the same behavior and constant value over all the velocities. The same results are also observed under S2 glass/epoxy specimen but this time a considerable increase value of absorbed energy is observed at 23º C and 40ºC temperature

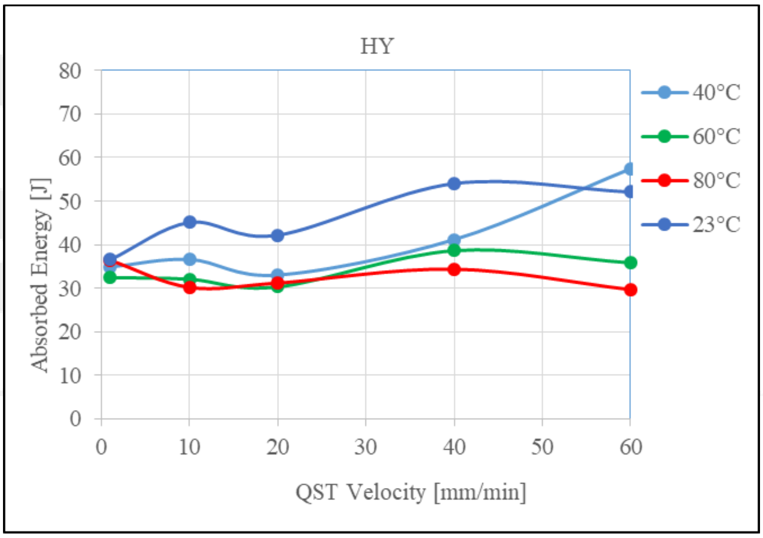


Figure 3.60 Absorbed energy versus QST velocity diagram under quasi-static test with hemispherical penetrator hybrid carbon-kevlar/epoxy composite

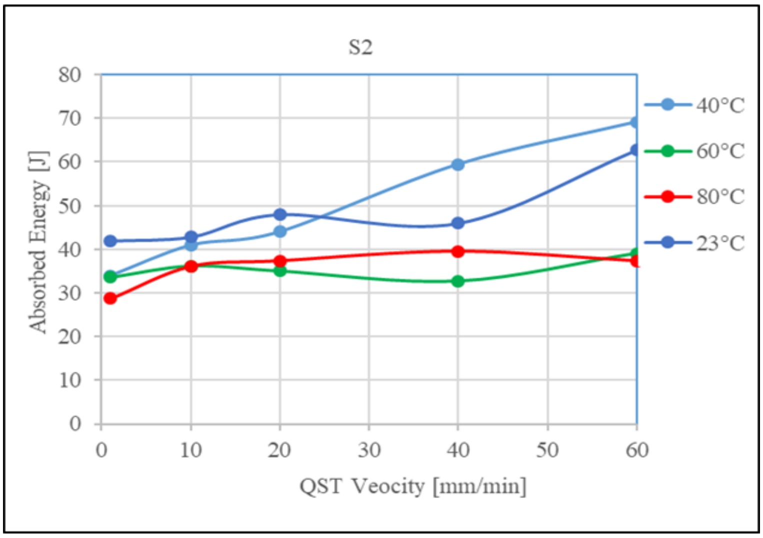


Figure 3.61 Absorbed energy versus QST velocity diagram under quasi-static test with hemispherical nose penetrator S2 glass/epoxy composite

CHAPTER FOUR
CONCLUSION

In this study, the thermal effects on quasi-static punch shear test and low velocity impact behaviors of laminated composite materials have been investigated experimentally. Laminated composites specimens were fabricated by vacuum assisted resin infusion method and cut into 100 x 100 mm dimensions. The specimens were subjected to impact energy of 40J, 60J, and 80J for low velocity impact test (LVI). For quasi-static test (QST) the specimens were subjected to 1 mm/min, 10 mm/min, 20 mm/min, 40 mm/min, and 60 mm/min velocities. During each experimentation the specimens were subjected under various adjusted room temperature of 23ºC, 40ºC, 60ºC, and 80ºC using two different types of intender nose (hemispherical tip and flat tip). From the force-deflection, absorbed energy of LVI and QST diagram for S2 glass/epoxy and hybrid carbon-kevlar/epoxy composite are compared. Considering absorbed energy and impact energy/quasi-static velocity diagrams as from the obtained results, the main conclusions are summarized as follows.

In the case of flat nose under the low velocity, the increase in the value of impact energy leads to greater increases in the value of contact force and the deflection of the specimen.

- Under the same conditions with the S2 glass/epoxy results, the behavior of specimen have been constant regardless of the increase of the temperature. As for the hybrid carbon-kevlar/epoxy, it is observed that during the increase of temperature the composite specimen lost its rigidity and strength.
- The contact force increases by increasing the temperature with a flat nose experiment where it can be observed that the S2 glass/epoxy specimen got the higher values of contact force than hybrid carbon-kevlar/epoxy specimen.

The observation from the hemispherical nose penetrators results inferred that hybrid carbon-kevlar/epoxy specimen presents the same behavior with only a rebounding occurred at 20J impact energy despite the increase of temperature. By increasing the impact energy, the contact forces were approximately the same but the deflection of the specimen increase.

- Under the same conditions, S2 glass/epoxy specimen presented also a constant reaction during the experiments with only a rebounding case at 20J and 30J of all the temperatures. Besides the 40 ° C, case where the contact force increased according to the impact energy the values of contact force remains nearly unaffected. The S2 glass/epoxy specimen present in general the higher peak contact force.

The results of flat nose graphs with quasi-static test of the composite specimens all put together showed a perforation at each energy and temperature level. The peak values of contact force are little bit higher than the low velocity impact flat nose case.

- With the both specimen an abrupt drop of contact force was observed after the formation of the plug. The uneven behavior of contact force and the various speed test has been observed despite the increase of temperature.

From the overall graph results of the hemispherical in quasi-static test nose penetrator it is shown that in the entire specimen every parameter put together undergone perforation.

- With hybrid carbon-kevlar/epoxy specimen the increase of test speed did not imply the increase of contact forces as a disproportionate evolution of contact force has been witnessed during the variation of temperature. The specimens here undergone a significant drop of contact after the failure of fiber.
- With the S2 glass/epoxy specimen in general the contact force increases as the test speed increases. After the fiber rupture without an abrupt drop of load, the friction zone observed has been considerable thereby increasing the displacement.

The energy absorption of S2 glass/epoxy specimen under flat tip intender during the low velocity impact present a considerable increase of its values while the impact energy increase. However, in quasi-static case it is observed a constancy of its value during the increase of the test speed. The higher values belong to low velocity impact.

- Under the same conditions the hybrid carbon-kevlar/epoxy specimen present a slight increase of absorbed energy for the low velocity impact during the increase of impact energy but remain constant at different test speed in quasi-static test.

The absorbed energy of S2 glass/epoxy specimen under the hemispherical nose increase when the impact low velocity and the test speed of quasi-static increase.

- Under the same conditions, the hybrid carbon-kevlar/epoxy specimen present the same behavior in both experiment but with the highest absorbed energy value observed in quasi-static test at 40°C.

From the observation of the punch shear strength results it can be seen that punch shear strength values of S2 glass/epoxy are similar to those of hybrid carbon-kevlar/epoxy for QST tests while these composites behave different for LVI tests.

Comparison between the two different penetrators show that at all temperature levels the largest amount of energy was for the S2 glass/epoxy specimen at 40ºC under the hemispherical nose intender. The S2 glass/epoxy specimen present high capacity of energy absorption as observed during the experiments considering all parameters and a good stability of results force contact-deflection diagram considered despite the variation of temperature. In case of energy absorption, the hybrid carbon-kevlar/epoxy specimen rather showed a better stability of curve because in two different experimentation method the values of absorbed energy were close to each other.

As recommendation for further studies low temperature effects on punch shear and impact behaviors can be studied in laminated and sandwich composite materials. Thickness in laminated composite and core and skin thicknesses in sandwich composite can be important parameter.

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APPENDICES

This section contains the design plans of the manufactured quasi-static test apparatus

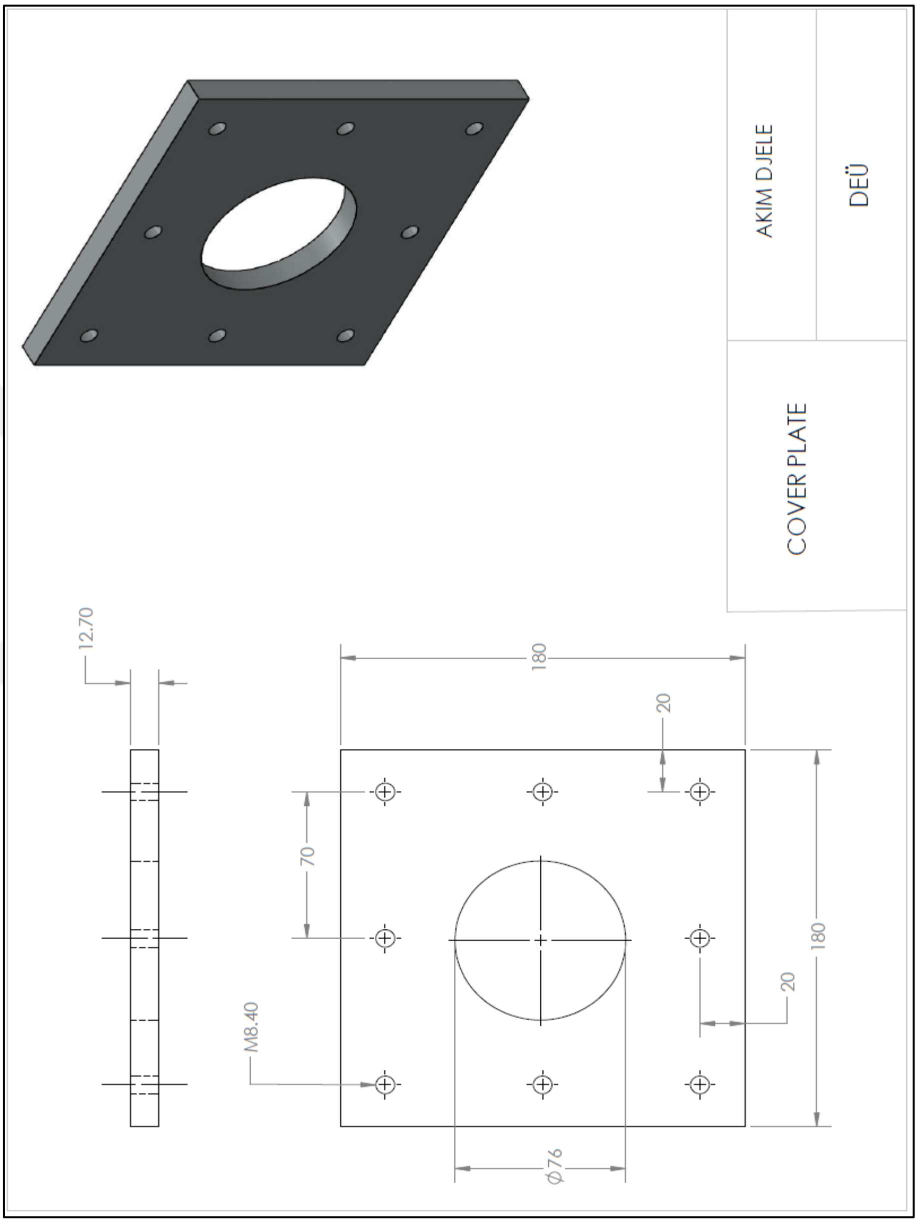


Figure A.1 Cover Plate

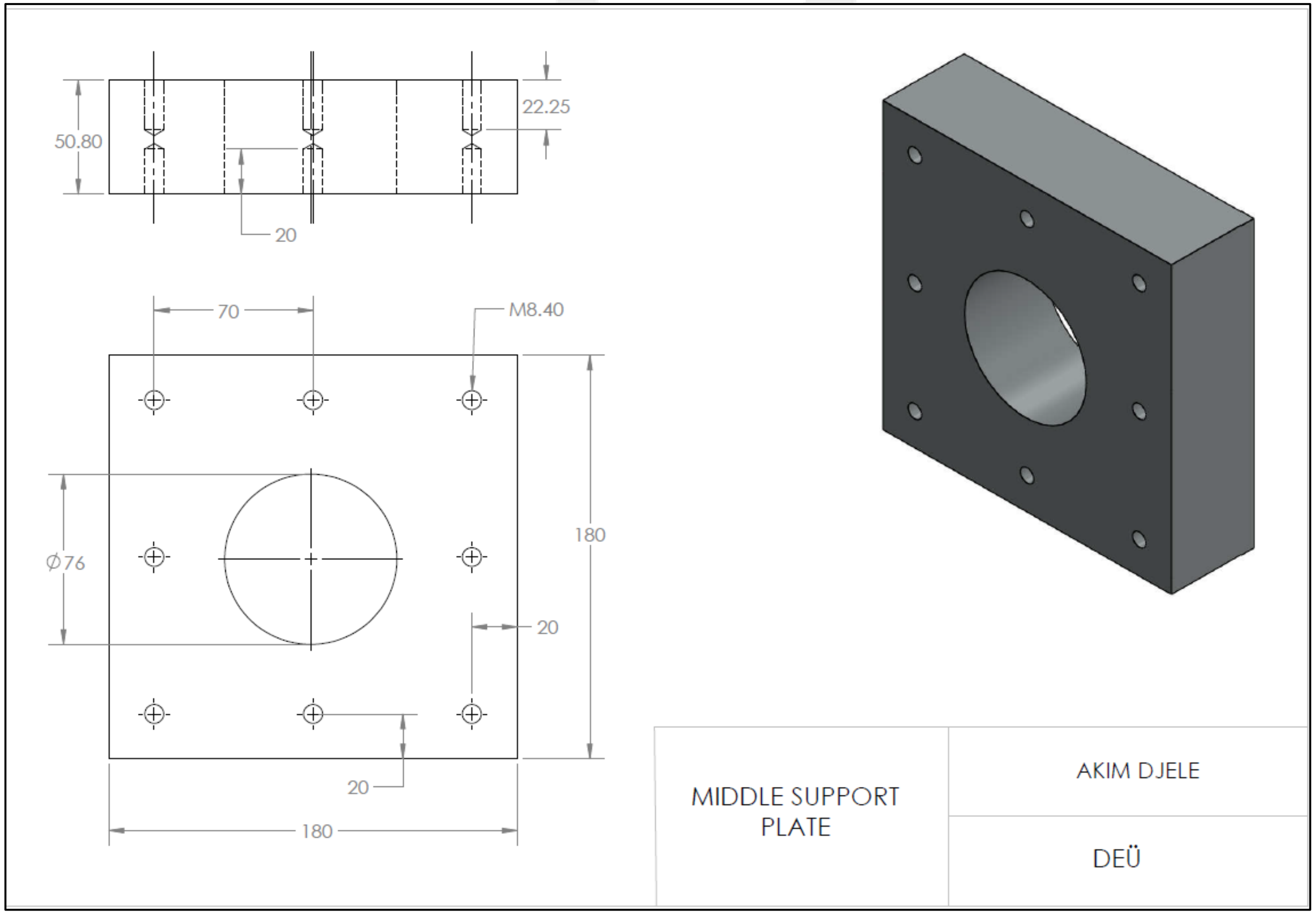


Figure A.2 Middle support plate

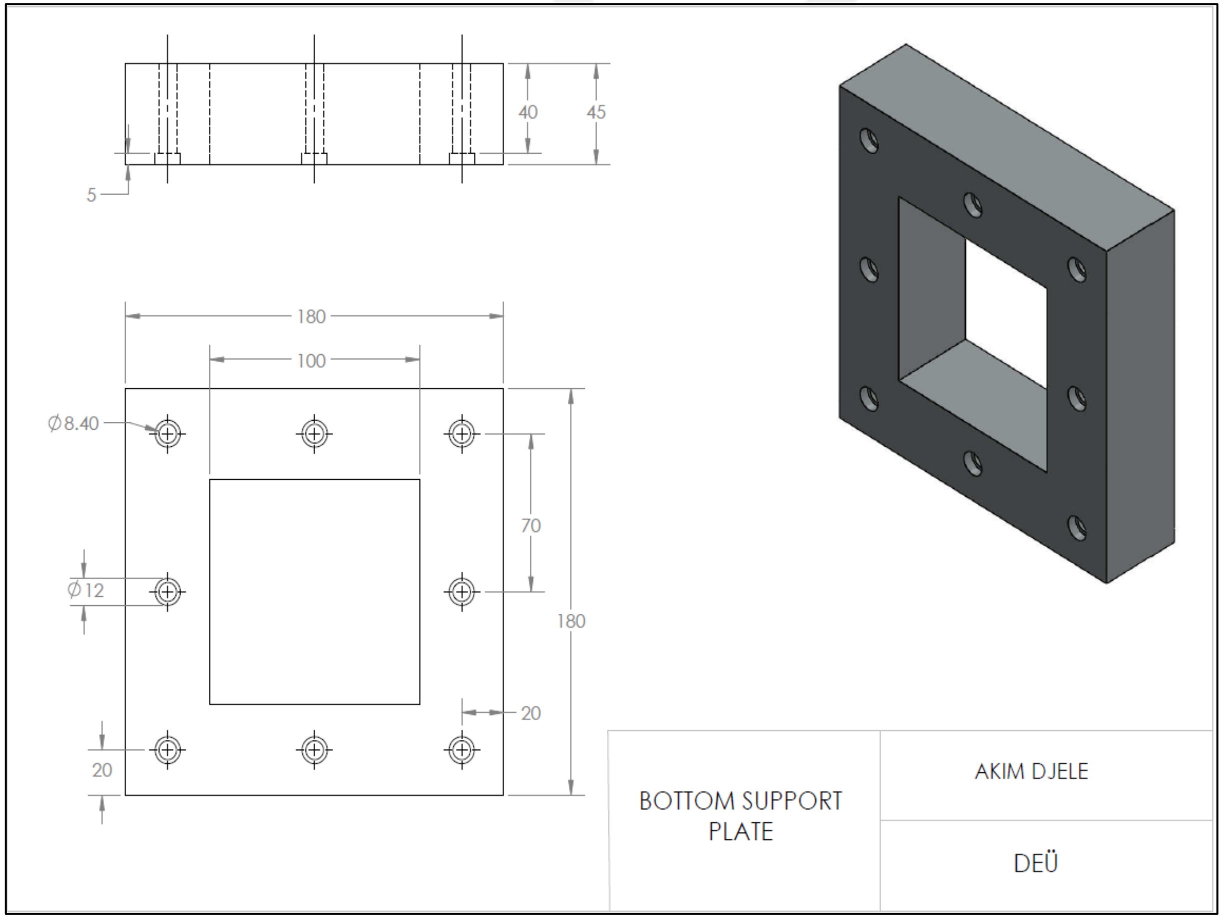


Figure A.3 Bottom support plate

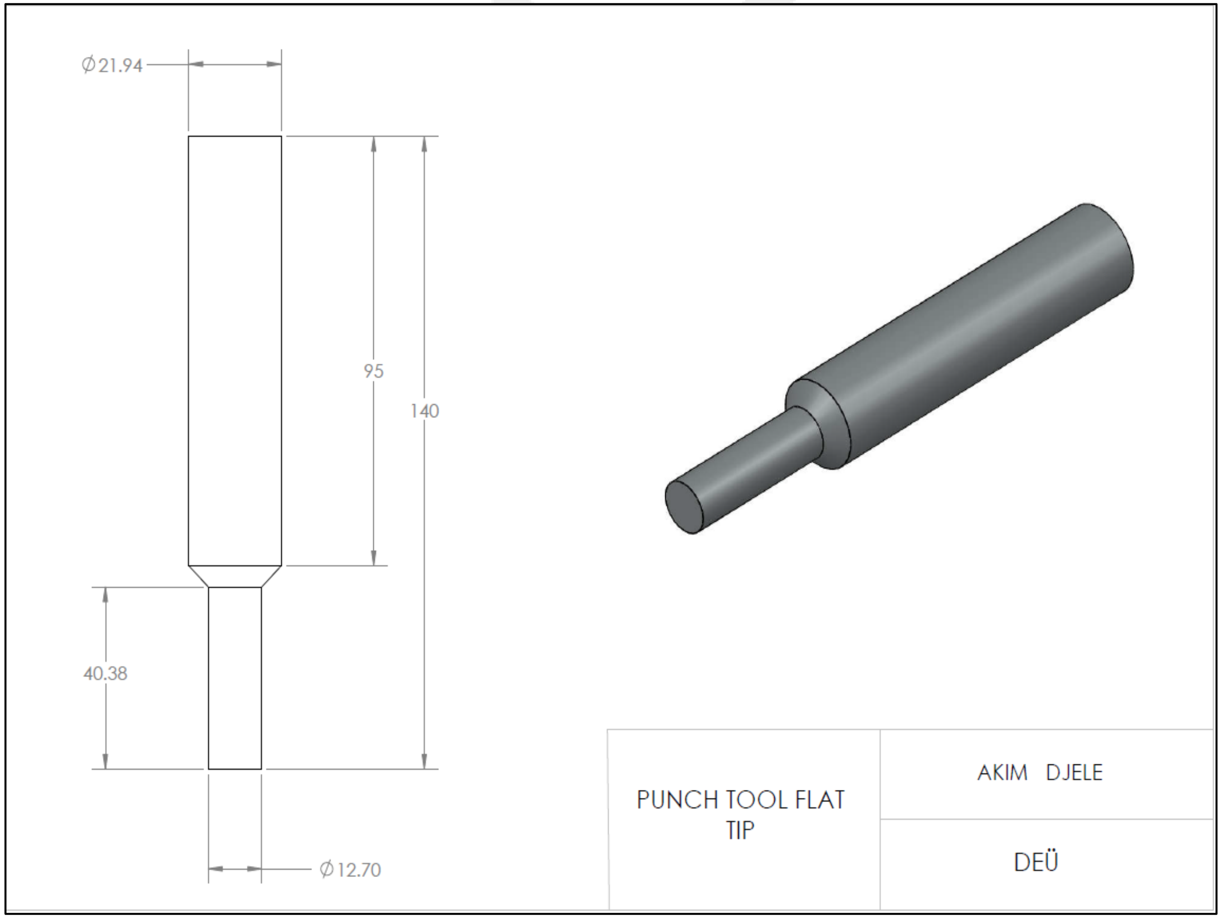


Figure A.4 Punch tool flat tip

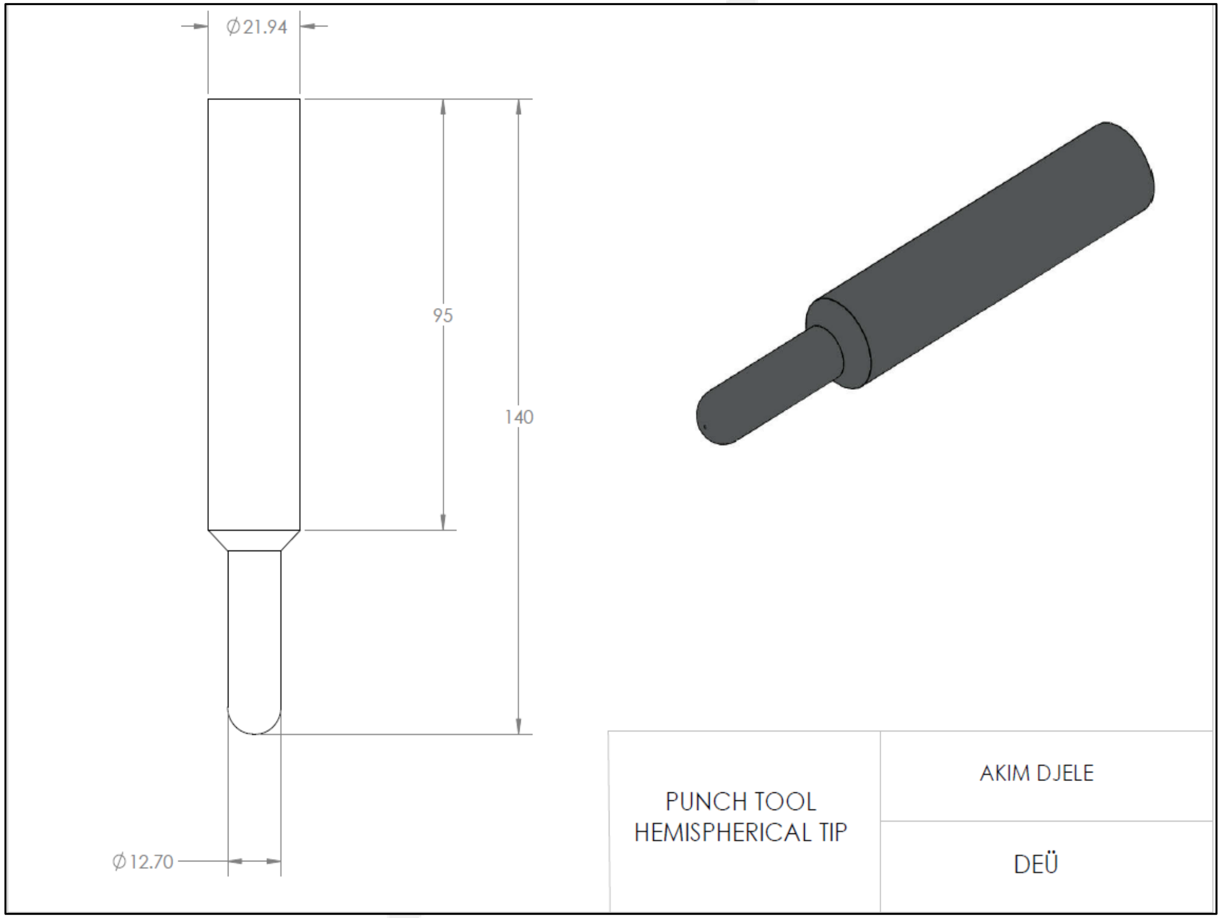
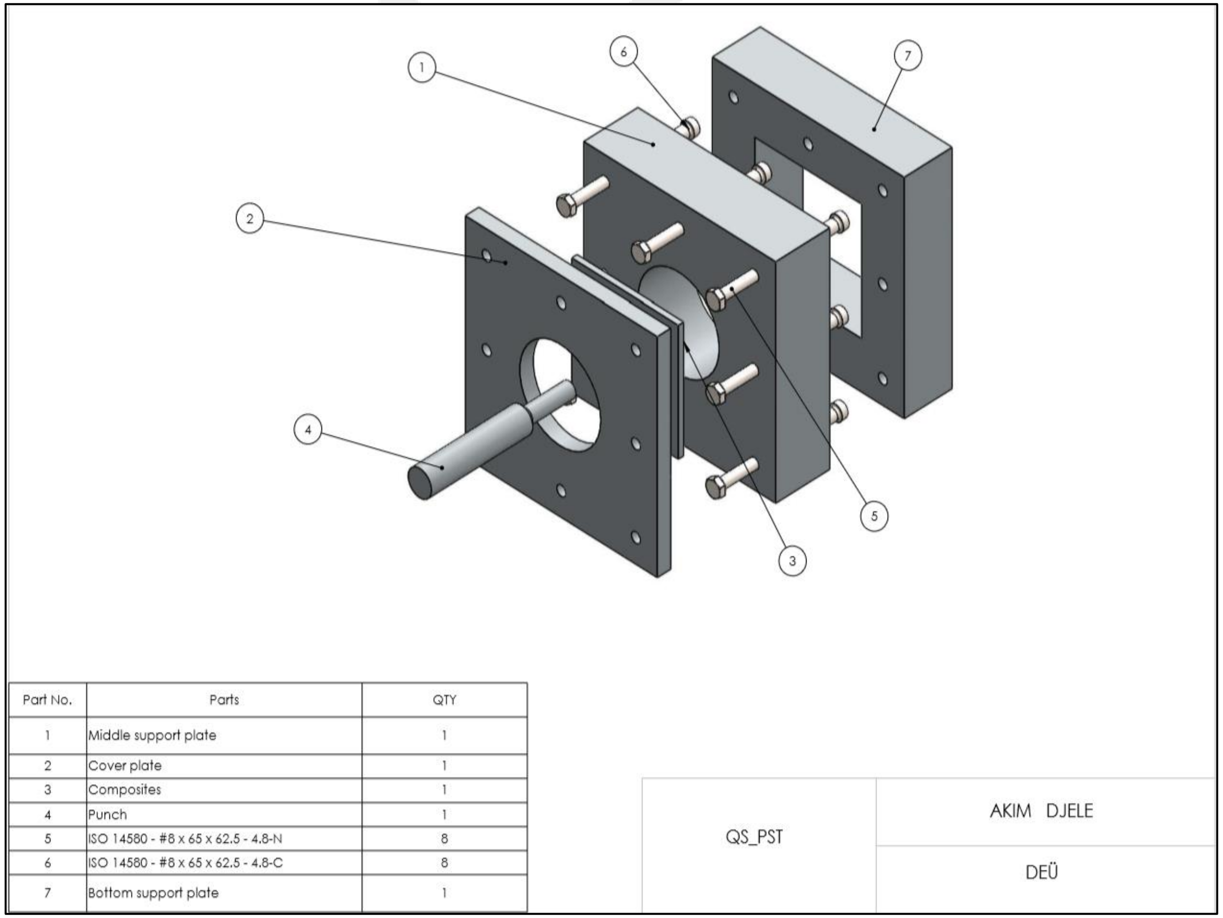


Figure A.5 Punch tool hemispherical tip



Part No.	Parts	QTY
1	Middle support plate	1
2	Cover plate	1
3	Composites	1
4	Punch	1
5	ISO 14580 - #8 x 65 x 62.5 - 4.8-N	8
6	ISO 14580 - #8 x 65 x 62.5 - 4.8-C	8
7	Bottom support plate	1

Figure A.6 Quasi static punch shear test