Development of a drop tower impact system for characterizing compressible foams under dynamic loads

by

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Vitæ

Jialiang Tao was born in Jiaxing, Zhejiang Province, P.R.China, in January 1994. He graduated from Harbin Institute of Technology, School of Astronautics, with B.Eng. degree in Engineering Mechanics. Subsequently, he started his Sc.M program in Mechanics of Solids at Brown University, School of Engineering, since September 2016. His research mainly focus on studying dynamics properties of soft materials by experimental methods.

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Dedicated to my family,

and to those watching over me.

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Chapter 1

Introduction

1.1 Mechanics of compressible, compliant and viscoelastic foams

Elastomer foams are widely used in impact protection applications, due to their ability to withstand large elastic deformation and absorb a large amount of energy during impact. Foam materials are suitable for protection, not only because they can weaken the transmitted impact energy, but also because they are lightweight. Lots of designers and engineers use foam materials to design impact protection products. For example, Lisa, Andrea and Silvia invented a kind of foam which is specified for impact protection and Robert F. Buckman had method and apparatus for body impact protection invented [1, 2]. Nevertheless, foam's inner structure is complex(Figure 1.1), which makes predictive models and thorough understanding do not exists. For the sake of utilizing the elastomer to their full potential, a predictive model for their time-dependent mechanical deformation is necessary. It is an attractive region and many people investigated about this topic in the past decades. In the late 1970s Princen H.M developed some simple 2D models of foam, in order to clarify the role of liquid fraction [3]. Later in 1990, the simulations of Bolton and Weaire showed how the gas and liquid in foams can influence their mechanical properties and disorder is crucial to the understanding of variation of their elastic properties [4]. Then,some other

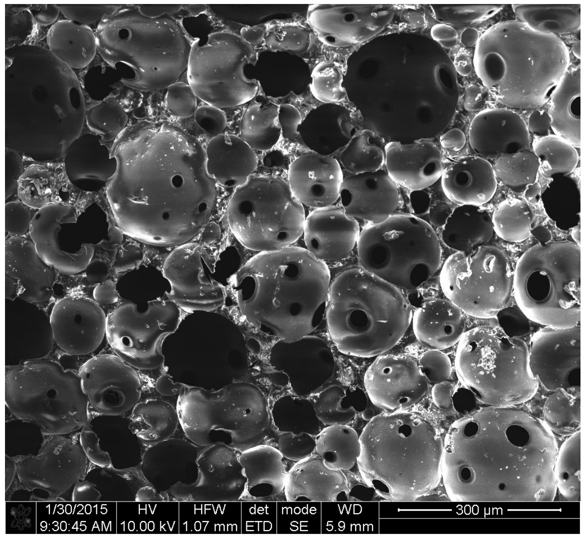

Figure 1.1: Image of XRD® foam taken using a focused ion beam

mechanical experiments are also set up to research the static and dynamic properties [5–7].

Due to the their varying responses to impacts of different strengths, it is crucial that elastomer foams should be studied at designated strain rates in order to understand their actual impact protection configuration. Materials respond differently under quasi-static loading conditions versus high strain rate loading conditions. This has been proved by experimental results [8]. Thus, designs of impact protection products such as phone cases, helmets, or other protective gear must consider the material response under specific strain rate conditions corresponding to the product environments. The foam we are going to test is from XRD® company. This company focuses on designing and producing sports impact apparatus. This can be used to decide the corresponding strain rate and the way to generate impact impulse.

1.2 Drop tower impact system

Figure 1.2 shows a digram of the range of strain rates which are typically of interest to researchers and corresponding test techniques. Its range spans from creep, which may last over years, to shock, which can happen in nanoseconds. Currently, the Instron Testing Machine can be used to generate strain rates from 10^{-4} s^{-1} to 10^{-1} s^{-1}, the Hydraulic Instron

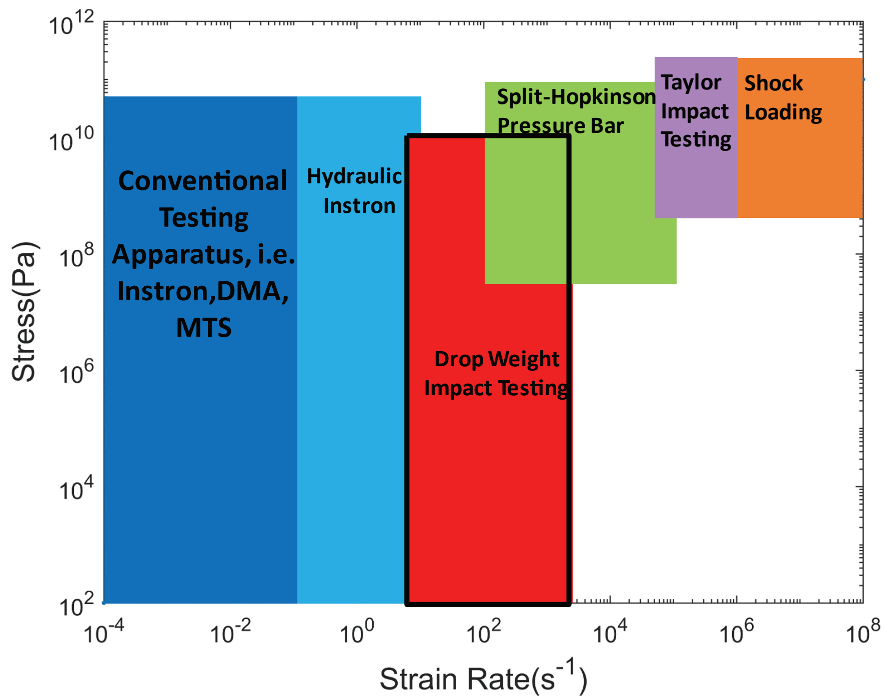

Figure 1.2: Strain rate Dependent Test Techniques

can generate strain rates from 10^{-1} s^{-1} to 10^{1} s^{-1}. They are all quasi-static situation. Drop-weight machines are also available commercially and standards have been written covering their design and use in the strain rate range from 10 s^{-1} to 10^{3} s^{-1}, which is the range for impact protection. Split Hopkinson pressure bars became the standard method of measuring material dynamic mechanical properties in the strain rate range 10^{3} - 10^{4} s^{-1} since 1970s and Taylor test can be applied for the cases whose strain rate is between 10^{4} - 10^{6} s^{-1}. They are used for estimating the dynamic strength of ductile materials in compression. The higher strain rate can be generated by Shock loading by plate impact or other explosive method [9].

The tested foam is for producing impact protect products. Foams are extensively used in energy absorption applications such as automotive crash safety systems, where compressive strain rates may reach 800 s^{-1} [10]. On the other hand, low speed crushes or impacts may produce a strain rate of 10 s^{-1} in the structure [11]. The strain rate range from 10 s^{-1} to 800 s^{-1} is suitable for Drop-weight machines. Thus, this project is undertaken to design and build a drop-weight impact testing (DWIT) system , typically a drop tower that can be used to characterize strain rates between 10 and 10^{3} s^{-1}. Elsewhere, this drop tower can be used alongside the Instron Testing Machines and the Split Hopkinson Bar in order to characterize an elastomer foam at a wider range of strain rates, thereby contributing a portion to a larger project that other researchers are also currently working on to characterize these materials. The tested material can also be other soft materials, such as hydro gel, silicone rubber or acrylic elastomer.

Chapter 2

Experimental Setup

In this chapter we will introduce the basic setup about the drop tower. It will include the introduction for mechanical structure of drop Tower, the alignment work, drop bar design, high speed camera set up and control system. The mechanical structure's design and assemble work with derivation of governing equations is done by Lauren Chanen [19].

2.1 1-D stress wave theory

Before we started designing the other parts of the experiments, we considered about the design for drop bars and the total height of drop tower firstly. Drop bar is a weight falls on foam specimen and apply the impact directly.

We assume when drop bar falls down, the air friction and other frictions are negligible, the section area of drop bars is equal to the section area of foam samples and foam material is homogeneous, isotropic and elastic. Then we derive the governing equation for the impact process. Figure 2.1 shows the free body digram for our setup and how the stress wave propagate in foam and drop bar. When drop bar falls from certain height and impact the surface of foam, stress wave is generated and propagated along the foam and drop bar respectively. The stress wave in foam can rebound between the top and bottom surface of it. Stress wave within drop bar can rebound on the top surface of drop bar. When stress wave

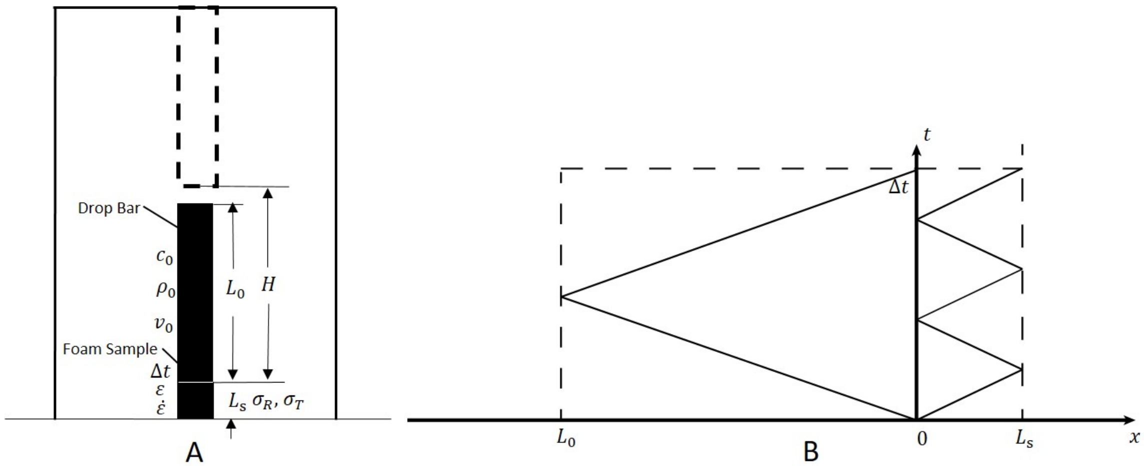

Figure 2.1: A: The free-digram for mechanical system B. The digram of stress wave front position versus time

is transmitted to the contact surface again, the impact process is over. The time duration for the impact process is decided by strain and strain rate.

$$\Delta t = \frac{\epsilon}{\dot{\epsilon}} \tag{2.1}$$

Transmitted stress can be derived from total strain and Young's modules, and stress of contact surface should be equal.

$$\sigma_s = \sigma_0 = E\epsilon \tag{2.2}$$

The average strain rate can be given by basic 1-D wave equation.

$$\dot{\epsilon} = \frac{1}{L_s}\left(-v_0 - \frac{\sigma}{\rho_0 c_0}\right) \tag{2.3}$$

Please notice that wave can impact and rebound. So the length of drop bar should equals to half of the distance wave has traveled.

$$L_0 = \frac{c_0 \Delta t}{2} = \frac{c_0 \epsilon}{2\dot{\epsilon}} \tag{2.4}$$

Combing all these equations and we assume it is free fall, we can get the drop height and

Table 2.1: Glossary of symbols for the governing equations.

Symbol	Definition	Value
Δt	Impact time	Unknown
ϵ	Total strain	0.25, 0.5 or 0.75
$\dot{\epsilon}$	Average strain rate	10 s^{-1}, 100 s^{-1} or 1000 s^{-1}
σ_s	Stress transmitted to foam	Unknown
σ_0	Stress transmitted to drop bar	Unknown
L_s	The thickness of foam sheet	12.5 mm
v_0	Impact velocity	Unknown
ρ_0	Density of drop bar	Decided by the material
c_0	Wave speed in drop bar	Decided by the material
L_0	Length of drop bar	Unknown
H	Drop height	Unknown
g	Gravity acceleration	9.8 $m \cdot s^{-2}$

the length of drop bar. The drop height can be given by:

$$H = \frac{v_0^2}{2g} = \frac{1}{2g}\left(L_s\dot{\epsilon} + \frac{E_s\epsilon_s}{\rho_0 c_0}\right)^2 \tag{2.5}$$

Table 2.1 shows glossary of symbols for all above equations. After we have acquired all the equations we need, we can use these equations to get the height of drop bar and drop tower. We used three kinds of materials to make drop bar, which were nitrile, polypropylene or Ultra-High Molecular Weight Polyethylene(UHMWPE). The density for nitrile, polypropylene and UHMWPE are 1000 $kg \cdot m^{-3}$, 933 $kg \cdot m^{-3}$ and 945 $kg \cdot m^{-3}$. The wave speed in Nitrile,Polypropylene and UHMWPE are 58.9 $m \cdot s^{-1}$, 105.4 $m \cdot s^{-1}$ and 854.49 $m \cdot s^{-1}$. These three materials have similar density, but different wave speed and can give us more space in designing drop bar and drop tower. On the other hand, these materials are all cheap and easy for modification, which can be helpful in making drop bars. Eventually we got the length and drop height for every strain and strain rate set up, which is shown in Table 2.2.

Table 2.2: Drop height and falling length for specific strain and strain rate

Strain rate	Strain	**-25%**	**-50%**	**-75%**
10	Material	Nitrile	Nitrile	Nitrile
	Height(m)	0.36	1.37	3.05
	Length(m)	0.21	0.47	0.74
10^2	Material	Nitrile	Polypropylene	Polypropylene
	Height(m)	0.62	0.81	1.55
	Length(m)	0.074	0.26	0.40
10^3	Material	UHMWPE	UHMWPE	UHMWPE
	Height(m)	4.78	4.96	5.14
	Length(m)	0.11	0.21	0.32

2.2 Mechanical structure of drop tower

Drop tower is the biggest mechanical device in the experiment. This tower is required to generate the designed strain rate and total strain applied on foam sample. From the height design table 2.1, we can find the highest required height is 5.56m(combing the drop height and length of drop bar together). Considering about the extra space for security reason, we need to have the total height higher than 5.8 m (19 ft.).

Directly building a 19-foot-height drop tower can be dangerous and inconvenient. Thus, the structure of drop tower should be transformable. When it is not working, it should be lower than 2.1 meters, which means its top can be reached and manipulated by people standing on the ground without ladder. When it is working, it can be raised and reached required height to generate designed drop impact. The main body of drop tower was designed to be composed of four structural box components made of T-slotted aluminum extrusions, nested inside of each other. The digram to show the raising order is shown in Figure 2.2. The whole structure was fixed on the floor by screws. In order to raise the whole structure, two electric winches are used to provide enough lifting force. When one box is raised, a pair of plates can be raised with box and overlap another pair of steel plates on a outside

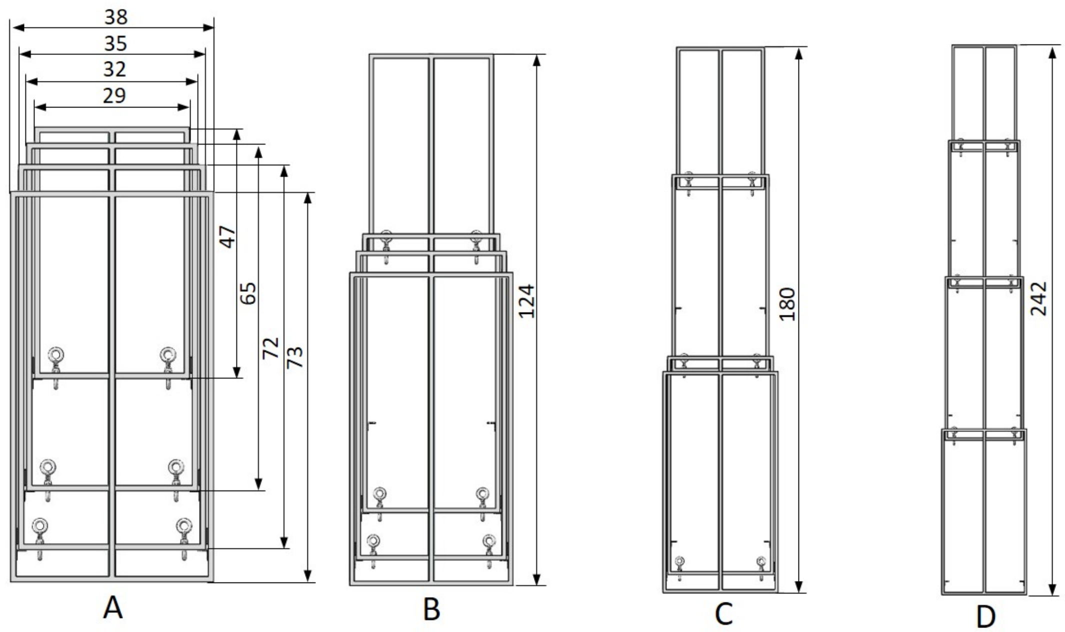

Figure 2.2: Dimension for drop tower (unit: inch): A.Sizes for four boxes; B.Height of tower when the first box was raised; C.Height of tower when the seconded box was raised; D.Height of tower when the third box was raised;

box, then screws can be used to connect the two parts and raised boxes can be fixed. When we need to raise the drop tower, firstly, before we start, we must check and make sure the installed parts are firm and solid enough. Then we run two winches simultaneously to pull and raise the innermost box. We must pay attention to the raising process and make sure the box is raised vertically without rotation, or it cab damage the metal frame. When the box is fully raised, we use screws to fix two pair of plates. Then repeat the above process until all the three layers are raised.

2.3 Stress and Strain measurement

In this experiment, we aim to analyze dynamic properties of foam. Thus, displacement data and load data are needed to be collected in this experiment.

We can get transmitted stress via load sensor. A Kistler®-9721B500 load sensor is used to collect data. This load sensor has good sensitivity (10mv$\cdot$lbf^{-1})for transmitted force ranged from 0.01 lbf to 500 lbf, which is wide enough to cover the expected load range. Its response time is shorter than 6 μs, which is much shorter than the impact time(range from 0.25-75 ms). In addition, its rigidity(5 lbf$\cdot\mu$in^{-1}) and natural frequency(70 kHz) are all very high, which means the sensor itself will not influence measurement process. During the impact process, it can be seen as a rigid body and has on dynamic responding for impact. The force signal can be transfered into electrical signal by load sensor, then USB-6211 Data Acquisition(DAQ) receives the signal and transmit it to computer. More details about data transmission is talked about in section 2.3.

The load sensor was attached on a base plate via screw. The head part of load sensor is not a whole plate, so foam specimen can not be placed on the load cell steadily. For this reason, we put a thin stack plate between the load sensor and foam specimen. Speckled foam sample was placed on the stack plate and drop bar can impact the specimen from vertical direction. For collecting displacement data, high speed camera need and other accessory will be used t provide a suitable optical environment. In this experiment, we can use a Photron® AX-200 mini camera. Its maximum resolution is 1024 $\times$ 1024 pixels with a corresponding frame rate to be 6400 fps. In order to provide a stable basement for the camera, it need to be placed on an optics table.

The size of foam specimen is very small. It is designed to be cubic whose length is 12.5mm to prevent buckling during compress process. We used the following accessory lenses: a Nikon® Micro-NIKKOR 105mm f/2.8 Lens, a 2x DGII Teleconverter, a 52mm close-up lens set. All these parts are for adjusting the focal length and zoom on the specimen. In order to provide enough lighting, 4-Wavelength High-Power LED Source produced by Thorlabs and a fluid laser guide are used.In order to remove light from Specular reflection, a pair of polarizer are used.

In the tests, we use clear PVC tube to guide the direction and position of drop bar. We also installed two small cameras for alignment work. The two cameras observe the direction of tube and load sensor from two different directions and their scope can be viewed in two monitors simultaneously. We installed a pair of perpendicular translation stages, attached

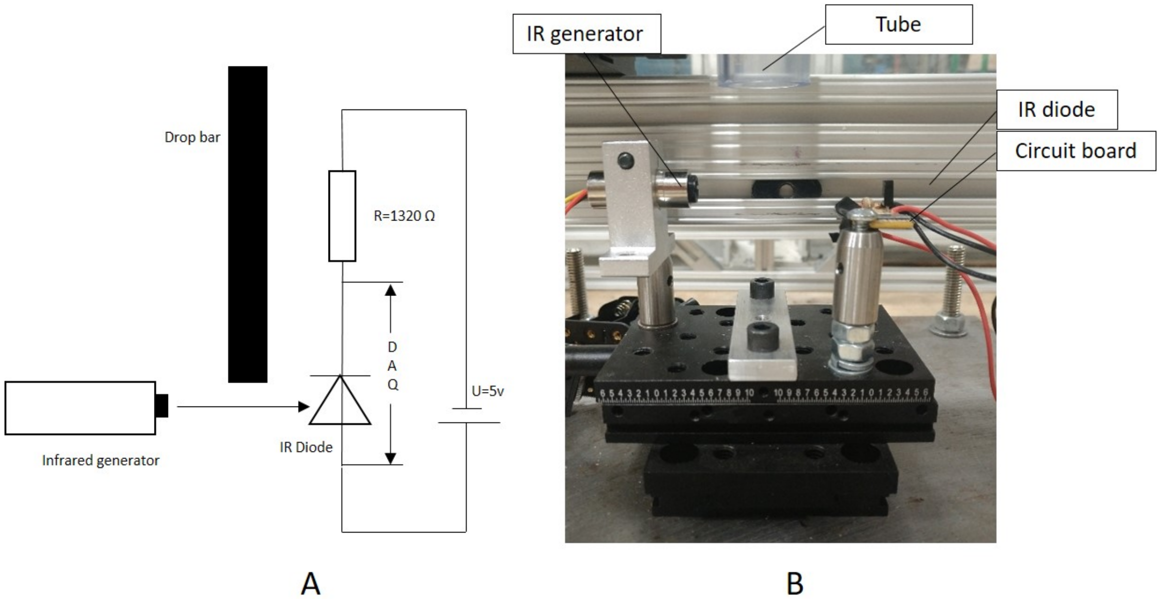

Figure 2.3: A.The designed circuit and mechanism for infrared lase detector. B. Photo for installed circuit board and infrared generator

on the tube and box. Another pair of translation stage is installed on the base plate to control the position of load sensor along the horizontal plane. We use translation stages to change its position until all the tubes are vertical to the ground and specimen localized in the center of tube.

Impact time is very short(range from 0.25-75 ms). The data collected by load sensor and images recorded by high speed camera are all time-sensitive. We designed a trigger to synchronize load sensor and high speed before impact happens. Here we adapted an simple infrared-based device to detect the position of drop bar. We put a infrared laser generator whose wavelength is 960nm on one side of the higher translation stage. When drop bar falls, it will block the infrared laser.

According to this circuit setup, we can have a falling TTL signal as a criterion to start recording. This falling signal was used as a trigger to activate the DAQ (Data Acquisition). When the signal is sent to the DAQ, DAQ is set to be activated by falling-edge signal and starts to work. The same falling signal is also sent out to high speed camera. It also starts to record impact video after it receives the signal. After the impact test is finished, we can output the video stored in camera's memory. The figure to show the process is show in Figure 2.3.

2.4 Full-field displacement and strain measurement

Surface deformation measurement of foam samples subjected to impact loading is an important task of this experiment. In order to test foam, various full-field non-contact optical methods must be applied to measure strain, such as the grid method [12] and digital image correlation technique(DIC). The size of foam samples are very small. On the other hand, frame rate of high speed camera is limited by camera's resolution. When the frame rate is higher, the resolution has to be lower for a certain camera. However, common DIC technique require a very high quality image with very high resolution to resolve the correlation between images. Thus, we use a newly-developed particle tracking technique, Topology-based Particle Tracking(T-PT) by Mohak Patel [13] to resolve displacement and strain field.

2.4.1 Evaluation of the effect of speckle and frame rate on displacement measurement

Before we started the actual experiment, as we were going to use a newly developed method, we needed to evaluate the error level of the new technique. In T-PT technique, the tracked object are featured speckles, rather than subsections. We need to figure out how the property of speckles and frame rates can influence the track results. This can help us to build up the criteria for designing pattern and set up camera.

Firstly, we used Matlab code to generated a reference picture. This picture is seen as the photo of undeformed specimen, as referenced image. It has black grounds and white dots. The dots stands for the pattern beads. The number of beads and size of the beads can be controlled by parameters in code. The brightness of every beads follow the gaussian distribution around the center of every bead. Then we compress the photo along vertical direction as shown in Figure 2.4. Then we set up the parameters for tracking algorithm

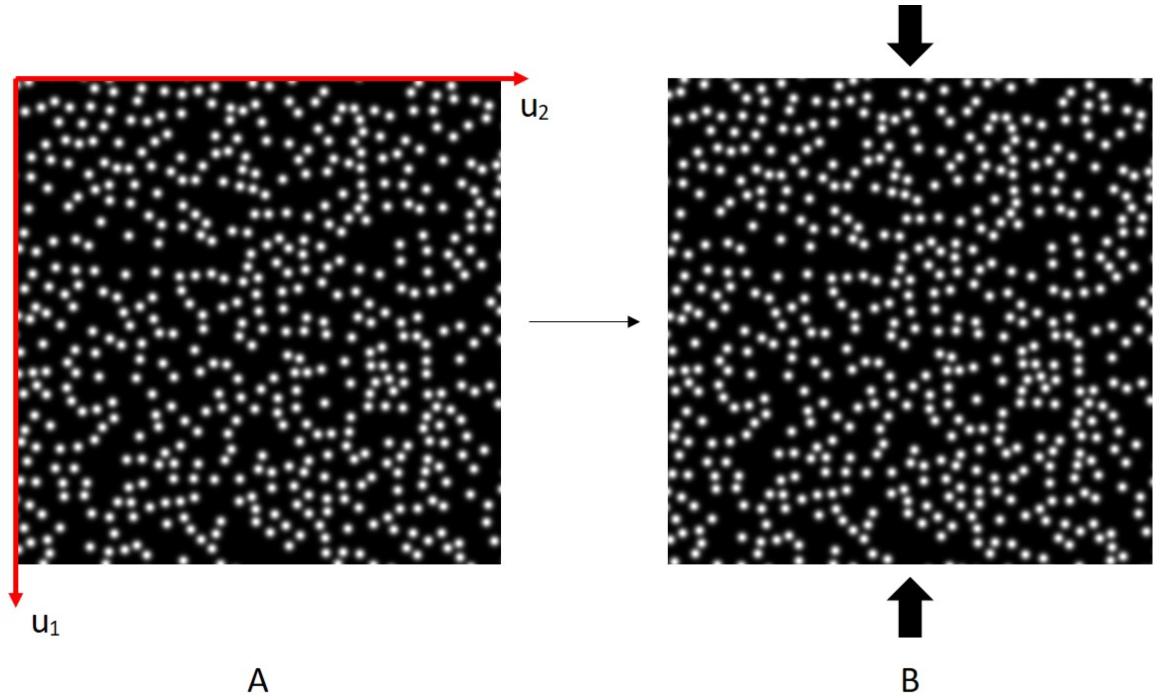

Figure 2.4: A pair of sample images when resolution is 768 pixels by 768 pixels. Number of beads is 500. Diameter is 7.8 pixels: A. Reference Image B. Deformed Image

and run tracking program to get the displacement field. The displacement field is known as a designed uniaxial compression, so we can compare the displacement field we get from T-PT method with the designed displacement and get the calculate error for the image. Beads are randomly distributed in the image but will not overlap each other. In order to reduce the error brought by its randomness, we need to iterate the process enough times and reduce the randomness of result.

Assume that we have n beads, the displacement we get form T-PT method is u_i for every particle, and the designed displacement is $\overline{u_i}$. We use following equation to evaluate the error level. All the results are in pixel unit.

$$\Delta u = \frac{\sqrt{\overline{u_i}^2 - u_i^2}}{n} \tag{2.6}$$

The simulation result is shown in Figure 2.5 We can find that the number of particles do not influence mean error significantly. However, standard deviation gets to be smaller as

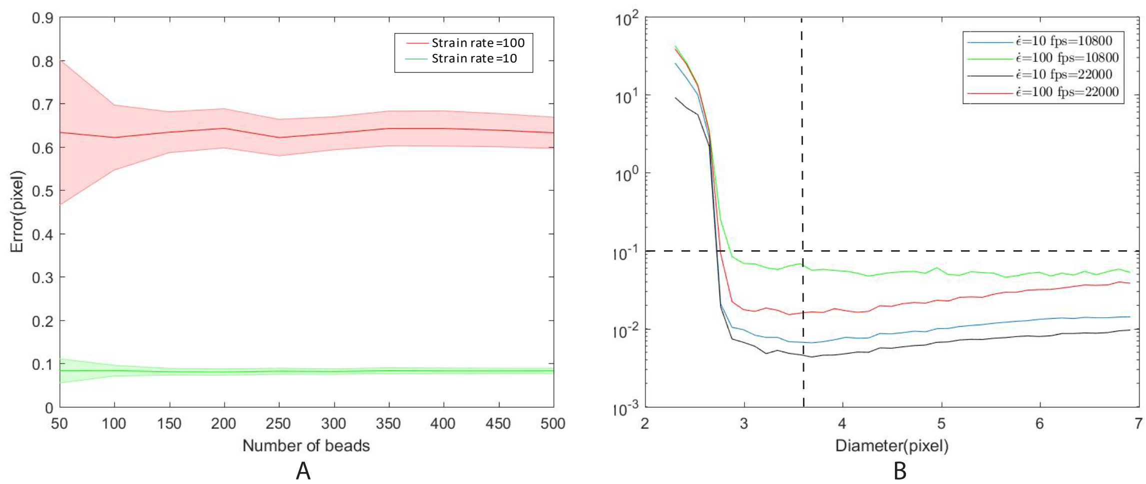

Figure 2.5: A.The relationship between number of beads and error level. B. The relationship between diameter of beads and error level

the number of beads get to be larger. According to Mohak's paper, more beads also require longer tracking time. Thus, although number of beads do not influence the mean error level, it can effect the stability of data and tracking efficiency.If the number of beads is too large, beads will overlap and make beads cannot localized. We also need a certain number of beads, distribute on different place of region to analysis the whole region displacement. After considering about these elements, we believe the number of beads need to be range from 200 to 500 in one image. For the following test, in order to get more stable data, we set the number of beads to be 500.

When bead's size is very small, the tracking error is very large and will reduce rapidly as the size get bigger. When diameter reaches around 3.6 pixels, error gets to lowest value and then increase slowly as the diameter get to be larger. When the bead is too small, it cannot be localized and tracked correctly. When it's bigger, gradually the track result tend to be effected by the center position. When it's too big, beads can overlap each other and their position cannot be tracked steadily. We can find that when diameter of beads equals to 3.6 pixels, the error is smallest. We define the error smaller than 0.1 pixel is "sub-pixel" error and we can find even if the size of beads is larger, error is still very small and is "sub-pixel". From the curve for different frame rates, we can find that when the frame rate is higher, error is smaller.

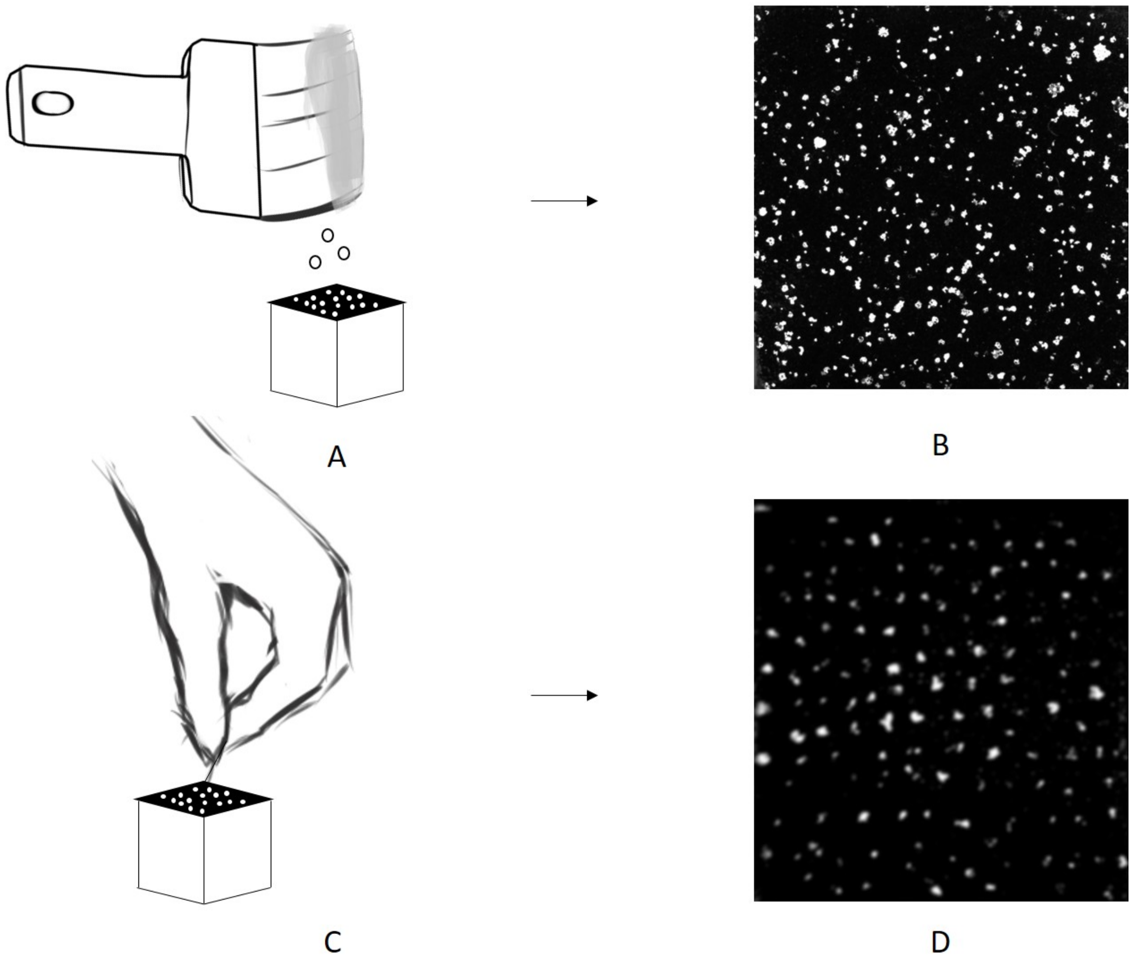

Figure 2.6: A.Digram for brush method B. Sample image of pattern get from brush method C.Digram for fiber method D. Sample image of pattern get from fiber method

2.4.2 Speckle pattern generation for low-resolution images

We developed two new methods to generation speckle pattern for low-resolution images: brush method and fiber method. We used air brush to spray black background on one surface of specimen. We dipped some pigment with a brush, buckled its bristles and then released them. Bristles would rebound to straight direction and threw out pigment drops. We put foam samples under the brush. Thrown pigment drops flew out and crush the surface of foam specimen and form pattern. This is how brush method works.

The second method is fiber method. This method is more straight forward. We picked up a very thin fiber, for example, a bristle from brush. We dipped a little bit pigment on one head of brush and used the head to slightly touch the surface of foam. Then a very little bead was formed. Repeat the process as many times as required number of beads. Finally we could get the pattern we need.

Generally, it's easier to get pattern by brush method. The number of beads is higher and size of beads is smaller in pattern method. However, its beads are still not totally discrete, which may cause some localization error. In addition, we need to notice that the size of beads is a bit too small, which is hard to set minimum beads size filer in code during T-PT analysis process. Thus, we use brush method to get the pattern used for quasi-static compression test and use the fiber method to get the pattern used for dynamic drop impact test.

2.5 Quasi-Static Compression Test

The final validation is a quasi-static compression test. We used the actual compression test to validate how T-PT algorithm works and whether it can work with inhomogeneity of pattern features. We used a compress device to compress a speckled specimen in a very low velocity. Meanwhile, we used a camera, not necessary to be high-speed camera, to capture its status in different time point. After we collected all the images, we used T-PT and mature DIC method to analyze its deformation. If both two methods can get similar result, we can confirm validation of T-PT algorithm.

In our test, the thickness of the foam was 12.63mm. Total displacement was 6 mm, test time was 1000 s, including the loading and unload process and interval between two neighbor images was 20 seconds. Approximately, the strain rate is less than 0.001 and can be seen as quasi-static. After we got the displacement field for the whole region, we used 2-D plane fitting to fit the relationship between displacement along compression direction and plane position. The slope of the plane, which is $\frac{du_1}{dx_1}$, can be seen as the strain. From Figure 2.7, we can see that the fitting result is still acceptable and the strain curve we got from T-PT

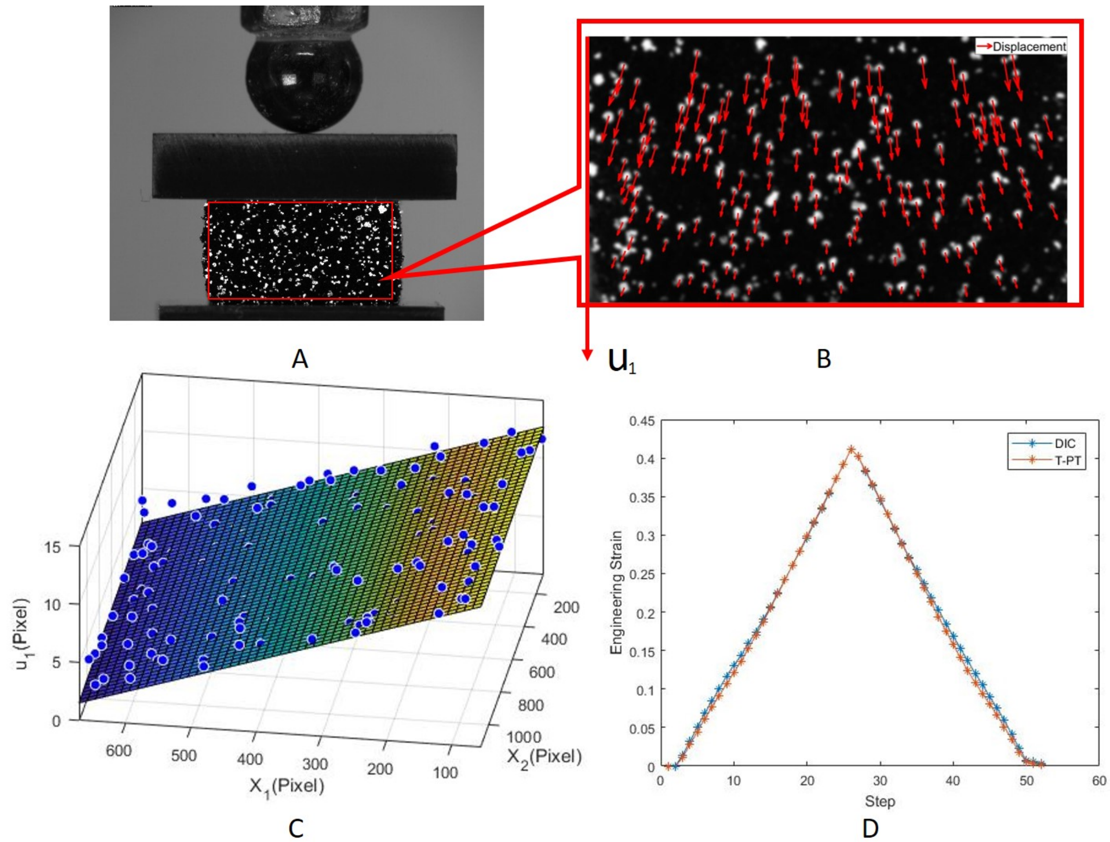

Figure 2.7: Figures for quasi-static compression test: A. Image of compressed foam specimen B.Displacement field get by T-PT method C. 2-D plane linear fitting result D. Strain result get by T-PT and DIC

method and DIC is very close. Thus, we think T-PT algorithm is suitable for this pattern and valid for getting strain data.

Chapter 3

Results and Summary

In our test, we set the frame rate to be 720 by 640 pixels and 13500 frames per second. This configuration can balance the resolution and frame rates. We set the sample rate to be 250 kHz, so that we can collect all the load data. Before starting a test, we need to raise drop tower to suitable height so that there is enough space for drop bar to fall and generate required impact. Then we install guide tubes, do alignment work carefully and make the center line of guide tube, foam specimen and load cell are in the same straight line. We install and turn on all the devices, including the high-speed camera, lighting device, infrared detector and DAQ. Finally, start control software of DAQ and camera, raise drop bar to designed height and release it with no initial velocity. When the drop bar fall and block the infrared laser, the trigger works and devices started to collect data. After the loading-unloading, process, the foam can jump and lose contact to the base plate. Our recording stops when foam leaves plate's surface. When impact finishes, we save the load data and image data, do the alignment work again and continue next test, until we finished all the required test.

3.1 PDMS compression test

Before we start out impact test on foam, we use our experiment set up to test mechanical property of PDMS (Polydimethylsiloxane). It is a kind of soft material whose mechanical material is known. The tested PDMS sample was made by pure Sylgard 184 and its mean elastic modulus is 1.72 MPa **??**. We use a 40 cm long drop bar, fell from 1.7 meter height to impact PDMS sample and get result in Figure 3.1. After getting the stress-strain curve, we use linear regression fitting to get its elastic modulus.The tested PDMS elastic modulus is 1.78 MPa, which is very close to the actual value. Thus, we think the test method is right.

3.2 The images procession

The sample images we collected during the drop process is shown in Figure 3.2. From the impact images we can find the compression was almost homogeneous, which proves our alignment work is successful. At the beginning of compression, the images are blurred a bit, but still acceptable for further T-PT analysis. Generally, the images are dark, but we can still distinguish the discrete particles by bold eye. We can find that the strain is higher than 75%, which is the highest designed strain. It means the compression process cover the all three different strains we need. After collecting the image recording the whole impact process, we can output the images from camera's memory. Before we analysis the images, we did some adjustment to improve contrast of images and make pattern features more visible. As we have mentioned, the localization algorithm is based on guassian distribution. Thus, in order to improve the accuracy of particle localization, we applied gaussian smoothing filters to captured images.

3.3 Strain and strain rate curve versus time

Then we can use T-PT code to get the strain and strain rate curve. For the sake of getting denser data points, we used spline interpolation to get three times more points. The strain and strain rate curve is shown in Figure 3.3. Our test included more cases, but under the other cases, the foam was compressed too severely and few particles could be tracked. Here we only present four reasonable cases with different drop height and different length of drop bar. From the strain-time curve, we can find that when the length of drop bar is longer or drop height is higher, the maximum strain is higher, because when dropped from higher

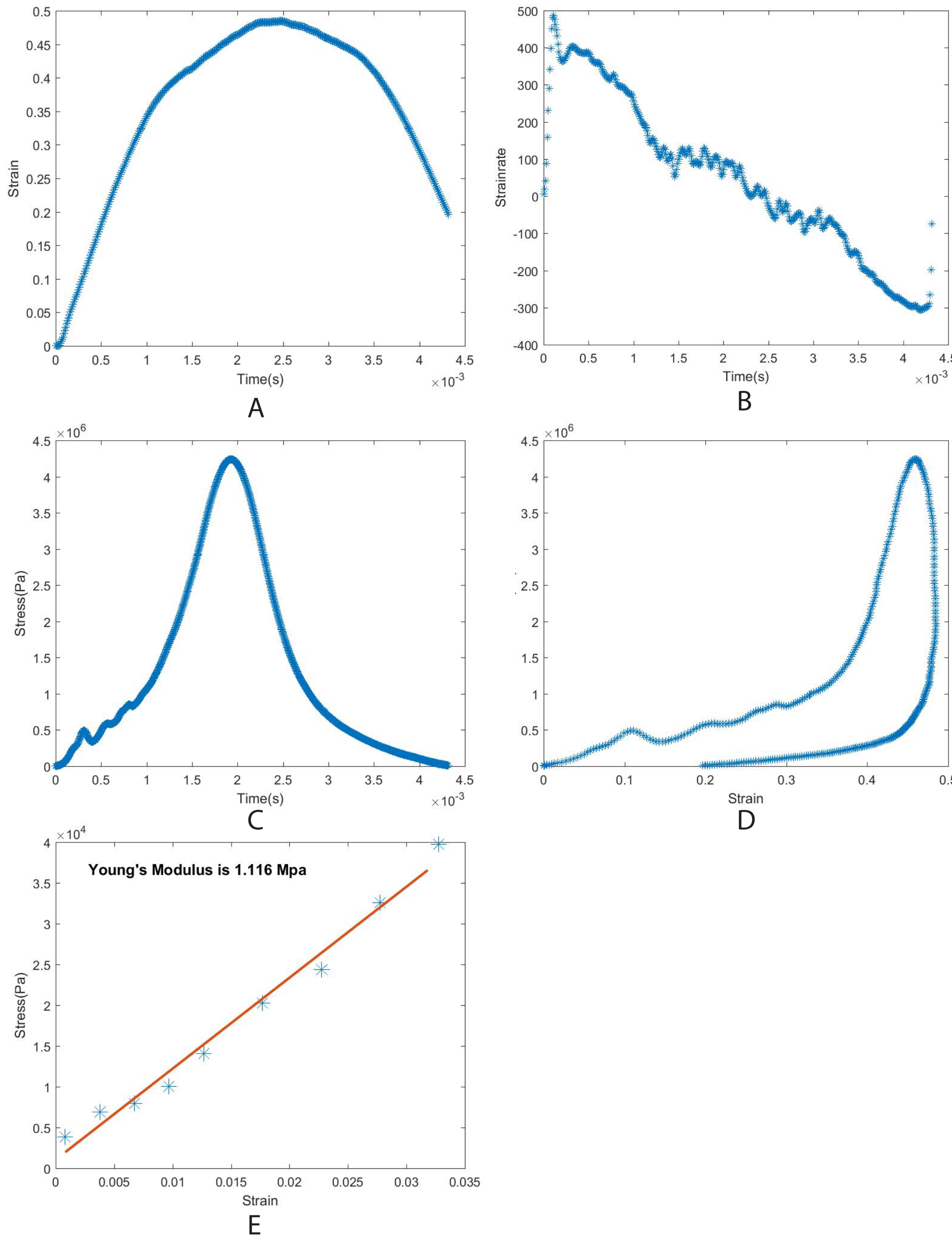

Figure 3.1: A. Strain-time curve for PDMS drop test B. Strain rate-time curve for PDMS drop test C.Stress-time curve PDMS drop test D. Stress-strain curve for PDMS drop test E. Linear fitting result

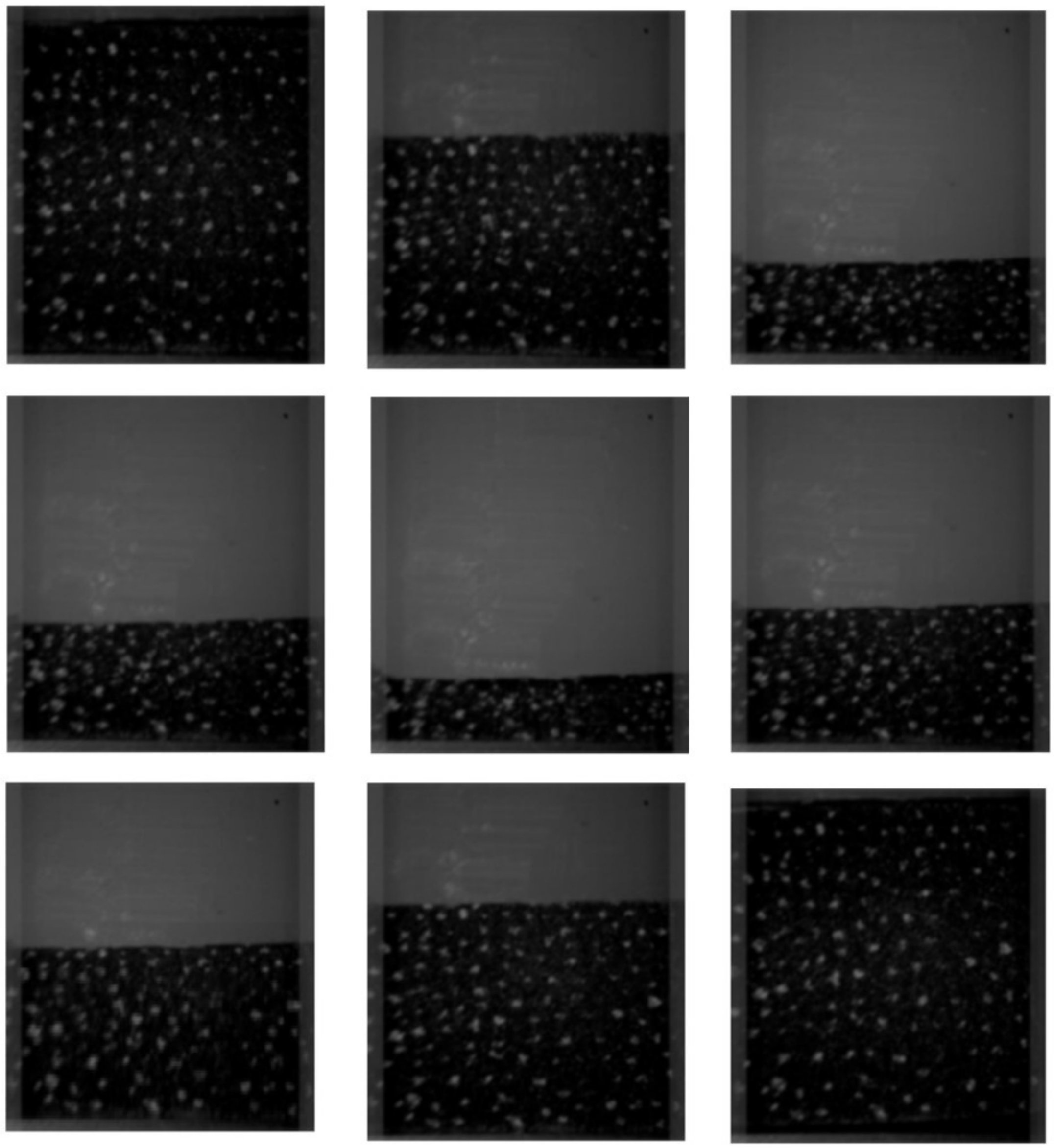

Figure 3.2: Figures for compression process of foam captured by high-speed camera: from loading to unloading. Resolution 720 by 640. Frame rate: 13500. Foam is impacted by a 40cm-long Polypropylene bar from 1.7m height

height or drop bar is longer, the foam needs to absorb more energy in impact process and deforms larger. From strain rate- time curve , we can find the maximum strain rate is more related to the drop height rather than length of drop bar. Actually, if we observe the images during the impact process, we can find that the maximum strain rate happens at the beginning of impact process when little energy has been absorbed by the foam. Thus, we can surmise at that time the strain rate is directly rated to impact velocity as the drop

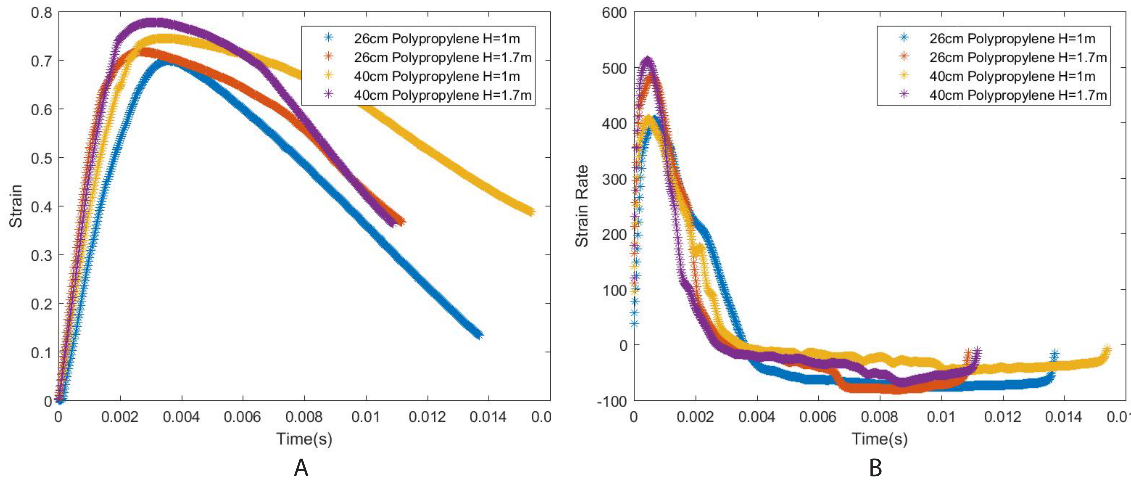

Figure 3.3: A. Strain-time curve for different cases B. Strain-rate curve for different cases

bar still conserve most of movement energy at that time point. The element to decide it is drop height, which is naturally related to maximum strain rate. If the drop bar is longer, the strain rate decreases slower, because longer bar can store more energy and take foam more time to absorb energy.

3.4 Strain and stress curve

Finally, we loaded the force data from stored file and matched it with corresponding time and strain data to plot stress-time curve and strain time curve in Figure 3.4 The stress curve is different from usual linear elastic loading curve. We need to pay attention to the unique thing that there is one or two small peaks before the curve reaches the highest stress. The peaks may be caused by the propagation and reflecting of stress waves between different surfaces. According to stress-strain curve, we can find that when under dynamic load, the responding of foam material is totally non-linear and different from static respond. Its deformation respond is severely hysteresis to its load respond.

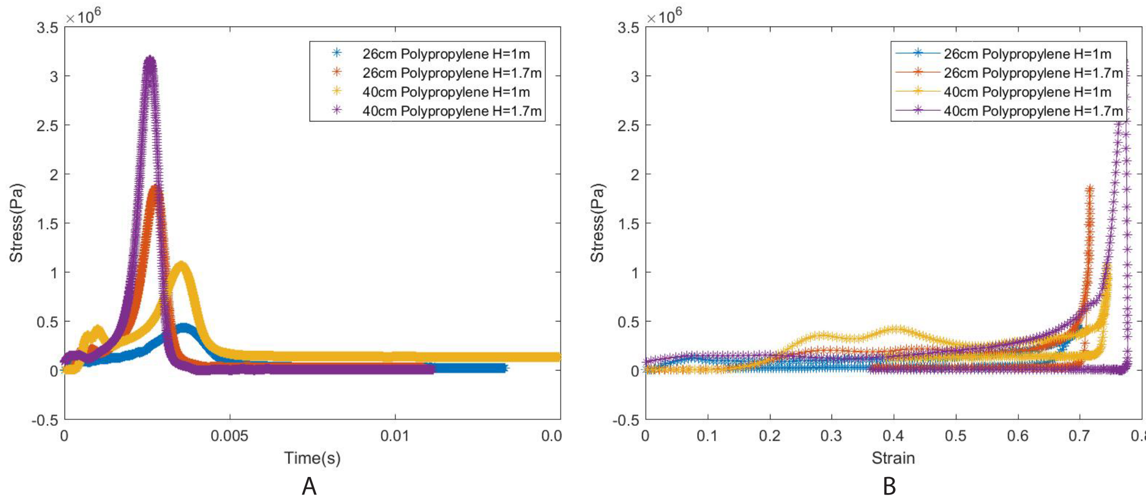

Figure 3.4: A:Stress-time curve for different cases B. Stress-strain curve for different cases

3.5 Summary

In this study, development of a drop tower impact system for characterizing compressible foams under dynamic loads is achieved. Based on the existing drop tower, we did further modification to its mechanical structure, made the raising process easier and safer. We gave a specific setup for alignment work, which is helpful in generate homogeneous impact. We designed and calibrated trigger system to synchronize high speed camera and Data acquisition. We spent more time on designing the pattern. In order to improve the performance of T-PT algorithm, we simulated the compress process and analyzed how the number of beads, size of beads, camera resolution and camera's frame rate can influence the error level of T-PT algorithm. We also tried and figured out successful method to apply tiny pattern on foam's rough surface. In the end, we executed drop tower test, collected preliminary data for some cases and analysis the result. We find the deformation loading of foam is much more hysteresis than its loading. When under dynamic load, it is absolutely non-linear material and cannot be predicted by traditional linear elasticity.

Our future work can include the following parts: First of all, although we have spent a long time on patterning work and found two methods to paint pattern on foam's surface, the two methods are still defective. We need to develop more advanced methods to generate tiny and round-shaped pattern. Secondly, our test is not fully complete. Our plan is to test different drop bar falls from different height. However, limited by the time and materials, we didn't have a chance to do that. Although we have cover the strain range from 0 to 75%, the strain rate didn't achieve 1000 s^{-1}. In the future, we need to do the test under different cases to study its response under wider strain rate range, ranged from 10 to 1000 s^{-1}. Thirdly, this set of devices, although now serving for foam material, we can expect it to be used to collect deformation and load data for other soft materials, such as hydro gel, silicone rubber or acrylic elastomer.

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