# Design of single piece sabot for a single stage gas gun

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**Abstract.** Single piece sabot is a vital part in single stage gas guns for impact testing in aerospace industries. Depending on the type of projectile used the design of sabot varies to accommodate the testing equipment. The velocity of the projectile exiting the barrel is dependent on the material and shape of the sabot used. The material selected for the design of sabot is rigid polyurethane foam, due to their low elastic modulus and low density. Two samples of rigid PU foam is taken and tests are performed to get their exact material properties. These properties are incorporated in numerical simulation to determine the best fit for practical use. Since the PU foams has a wide range of porosity which plays a prominent role in deciding the exit velocity and accuracy of the projectile coming out of the barrel. By optimisation, to the best suitable material sample can be determined.

## 1.  Introduction

Single stage gas guns are used for performing impact tests in aerospace industries due to the high velocity it generates [1]. Sabot is a vital part in a single stage gas gun that holds the projectile inside the barrel. These projectiles vary in mass, size and shape depending on the type of test carried out. Since it is not feasible to have different test equipment and different setup for each test, a sabot is used. In order to get the maximum velocity at the end of the barrel, the material used for design of sabot should be of low density and low modulus of elasticity. Rigid PU foams [3] exhibit these above properties, but the range of their properties is very wide. So two samples of different densities are taken into consideration and tests are performed to obtain their exact material properties and numerical simulation is done.
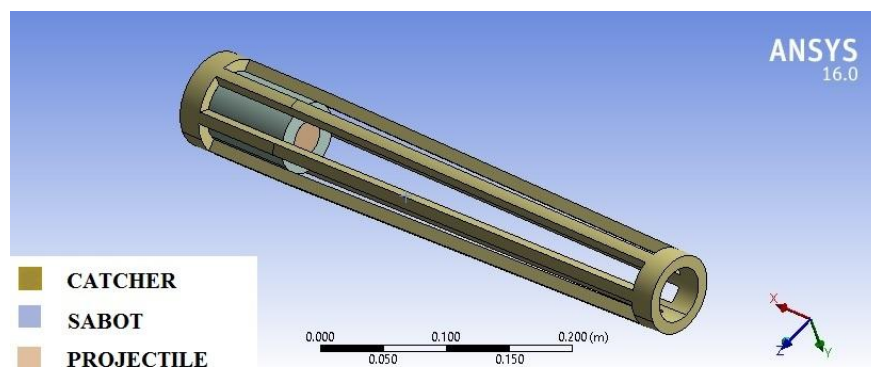


**Figure 1.** Catcher, Sabot and Projectile Assembly

The single stage gas gun consists of a pressure chamber connected to a barrel and a valve in between. When the testing is to be carried out, the projectile is loaded in it. Now the opening of the valve at required pressure from the rear side of the barrel, shoots the projectile at a very high velocity to hit the target. With varying projectile specimens, the size and shape of the barrel has to be changed to perform the test. The use of a sabot enables the use of a single barrel to hold the projectiles of different sizes. Sabot, not only support and position the projectile inside a barrel, but also provide proper sealing and prevents projectile to have pitch and yaw motions in its path. As soon as the valve is opened, the sabot and projectile starts at the same velocity, but sabot stays behind inside the barrel. This is done with the help of a catcher system. This catcher is a tapered cylindrical part placed inside a barrel to make sure the sabot gets crushed inside it. The assembly of the catcher, sabot and projectile system is shown in the Figure 1. The catcher is divided into two sections. The rear part is cylindrical, where sabot and projectile are loaded. The front part is tapered, to arrest the sabot when valve is opened.

Sabot is made of PU Rigid foam, a polymer foam, casted by reacting a di- or poly-isocyanate with polyol. The porosity of the casted foam can be varied easily by changing the proportions of the mixtures. So, Samples of two different density are taken and tested for mechanical properties. To obtain these mechanical properties, tensile and compressive tests are done on each specimen for different Samples.

## 2. Material testing

Two different samples of PU foams with difference in their densities are taken into consideration.

**Table 1.** Density of Sample A and Sample B

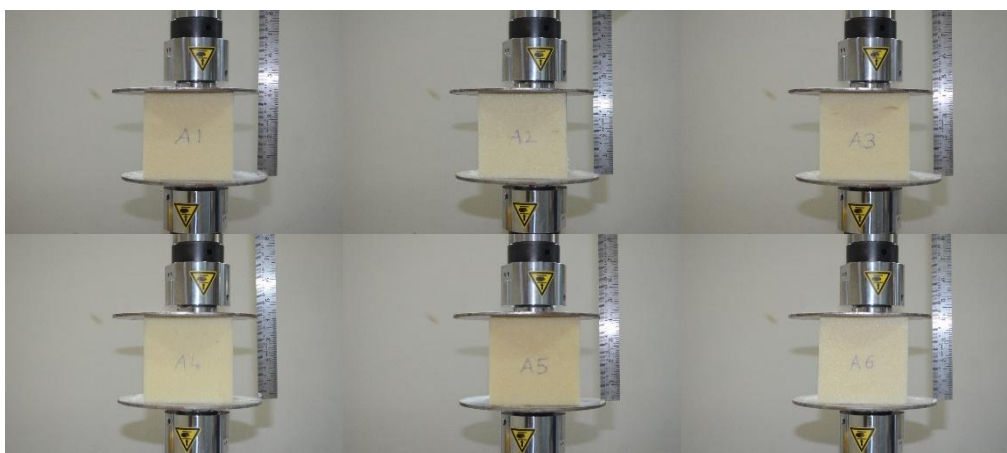| Sample name | Density (g/cc) |
| --- | --- |
| Sample A | 0.050340 |
| Sample B | 0.080823 |



**Figure 2.** Specimens of Sample A before Compression Test

### 2.1 Compression Test

The specimens for compression test are cube of dimensions 100 mm per side. Figure 2 shows the specimens of Sample A, set in compression testing machine. Figure 3 shows the specimens of Sample B.

**Figure 3.** Specimens of Sample B before Compression Test

The compression test is carried out at a deformation rate of 15mm/min [4]. Figure 4 and Figure 5 shows the specimens of Samples A and B respectively. From the Figures, it is quite evident that the Sample A deforms more than Sample B.
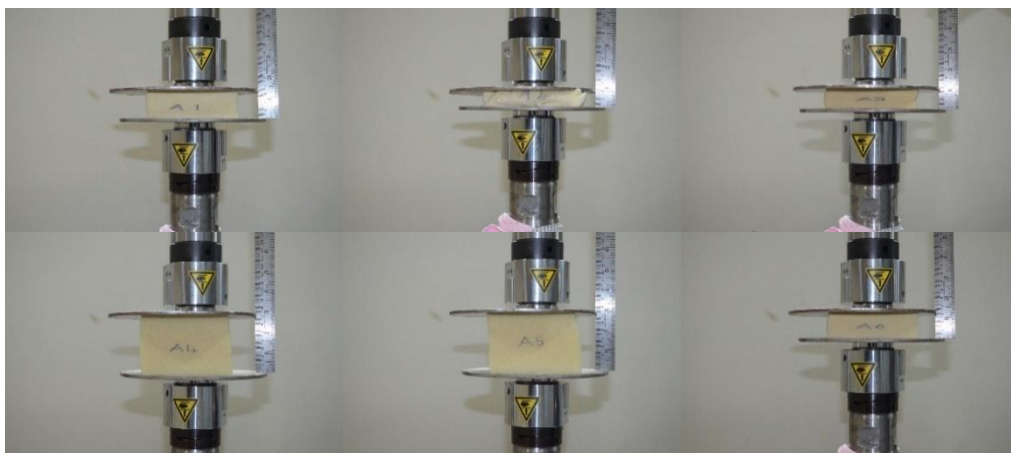


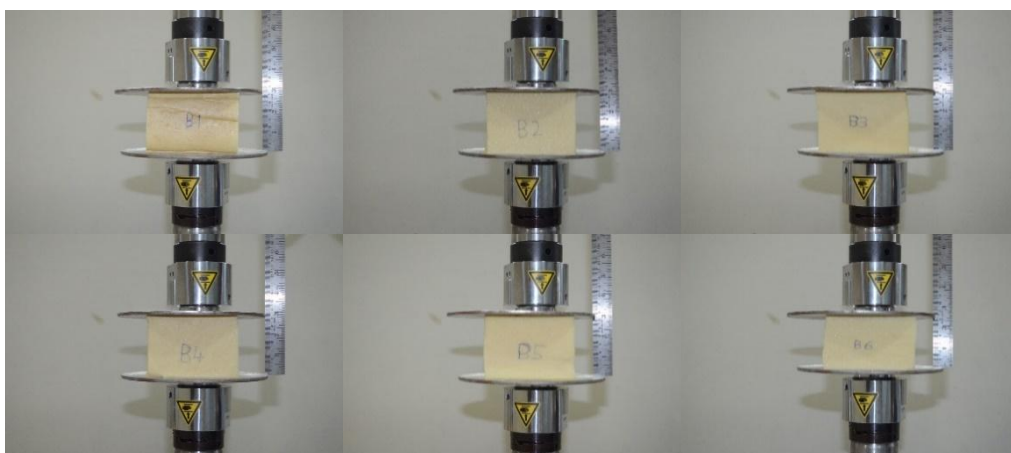**Figure 4**. Specimens of Sample A after Compression Test



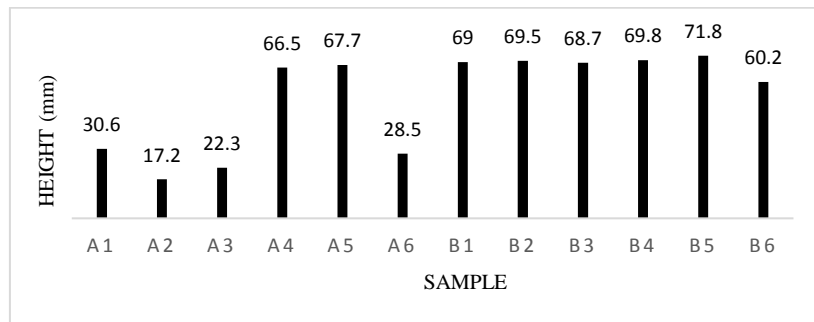**Figure 5.** Specimens of Sample B after Compression Test

**Figure 6.** Compressed Heights of Sample A and Sample B

The comparison of the height of specimens of both sample A and B after the compression test is shown is Figure 6

*2.2 Tensile Test*
Tensile specimens of both Sample A and B are made according to [5] ASTM D1623-09. Figure 7 shows the specimens cut from the 100 mm casted cubes.
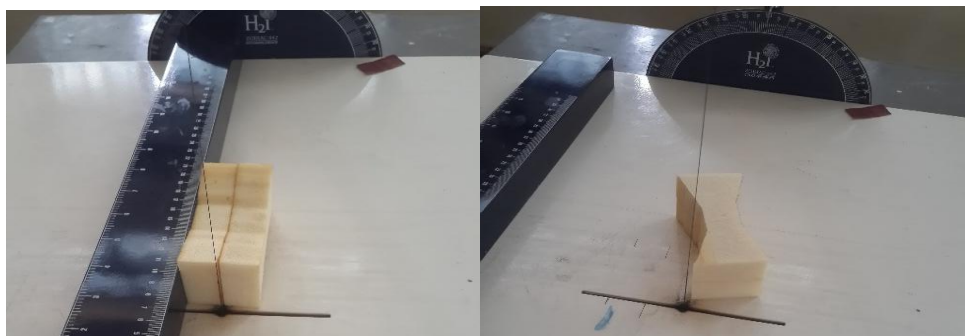


**Figure 7.** Specimens cut according to ASTM Standards

The test specimen dimensions between the tapered holding areas is cube of 25.4 mm. To accommodate the holding area of the specimen, a wooden fixture is made, since a metal fixture would crush the specimen. Figure 8 and Figure 9 shows the tensile specimens of Samples A and B respectively held in the tensile testing machine before the test carried out.
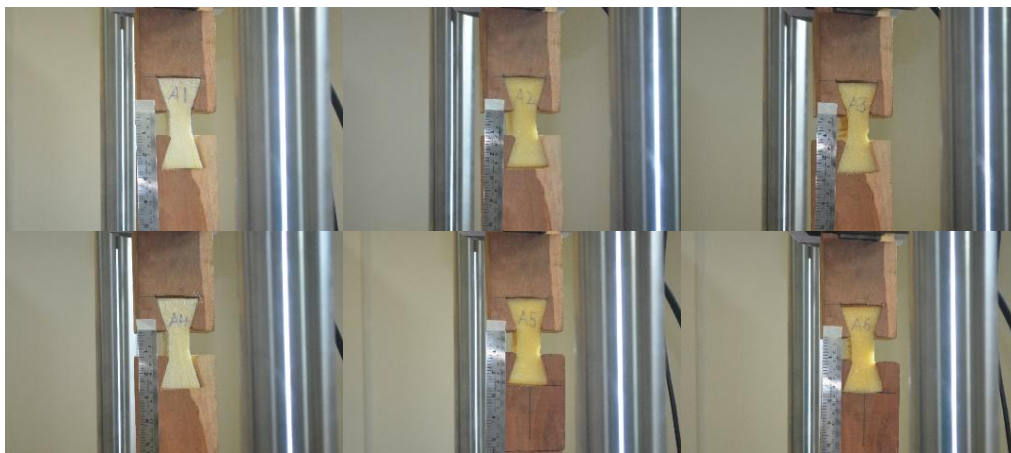


**Figure 8.** Specimens of Sample A with wooden fixture before Tensile test
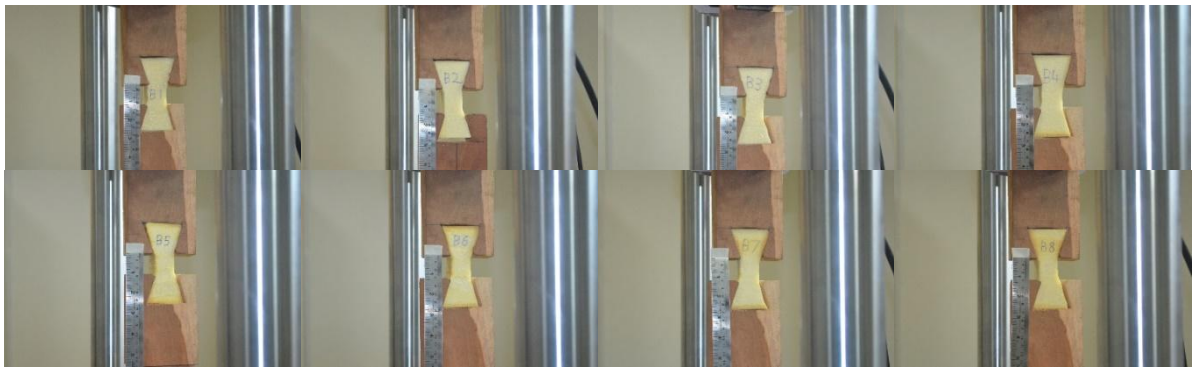
**Figure 9.** Specimens of Sample B with wooden fixture before Tensile Test

The tensile test is carried out at a deformation rate of 6 mm/min. Figure 10 and Figure 10 shows the specimens of Samples A and B along with wooden fixture. From the Figures, one can see that the Sample A is soft and has higher Elastic Modulus than Sample B.
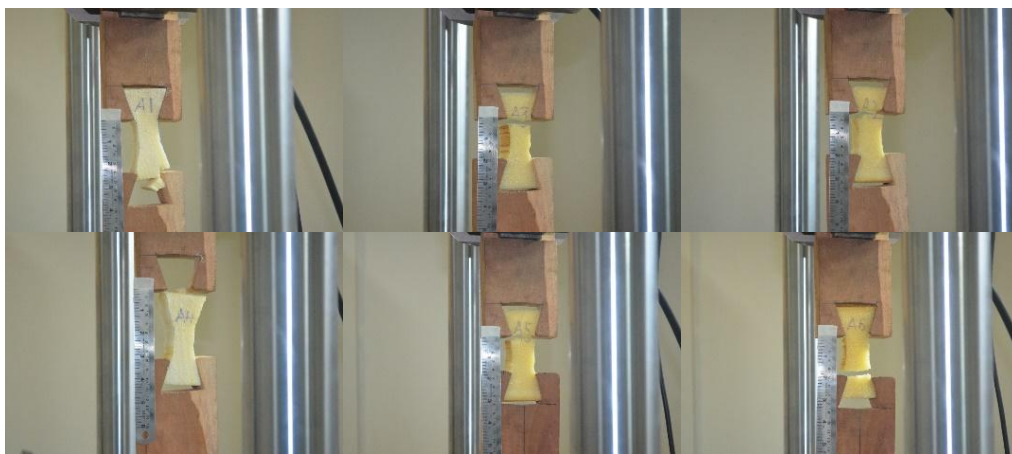


**Figure 10.** Specimens of Sample A with wooden fixture after Tensile Test
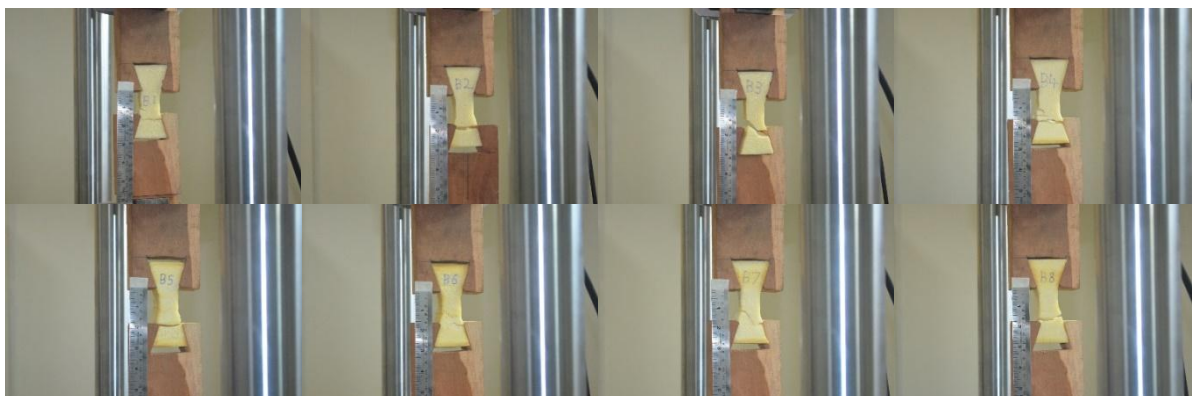


**Figure 11.** Specimens of Sample B with wooden fixture after Tensile Test
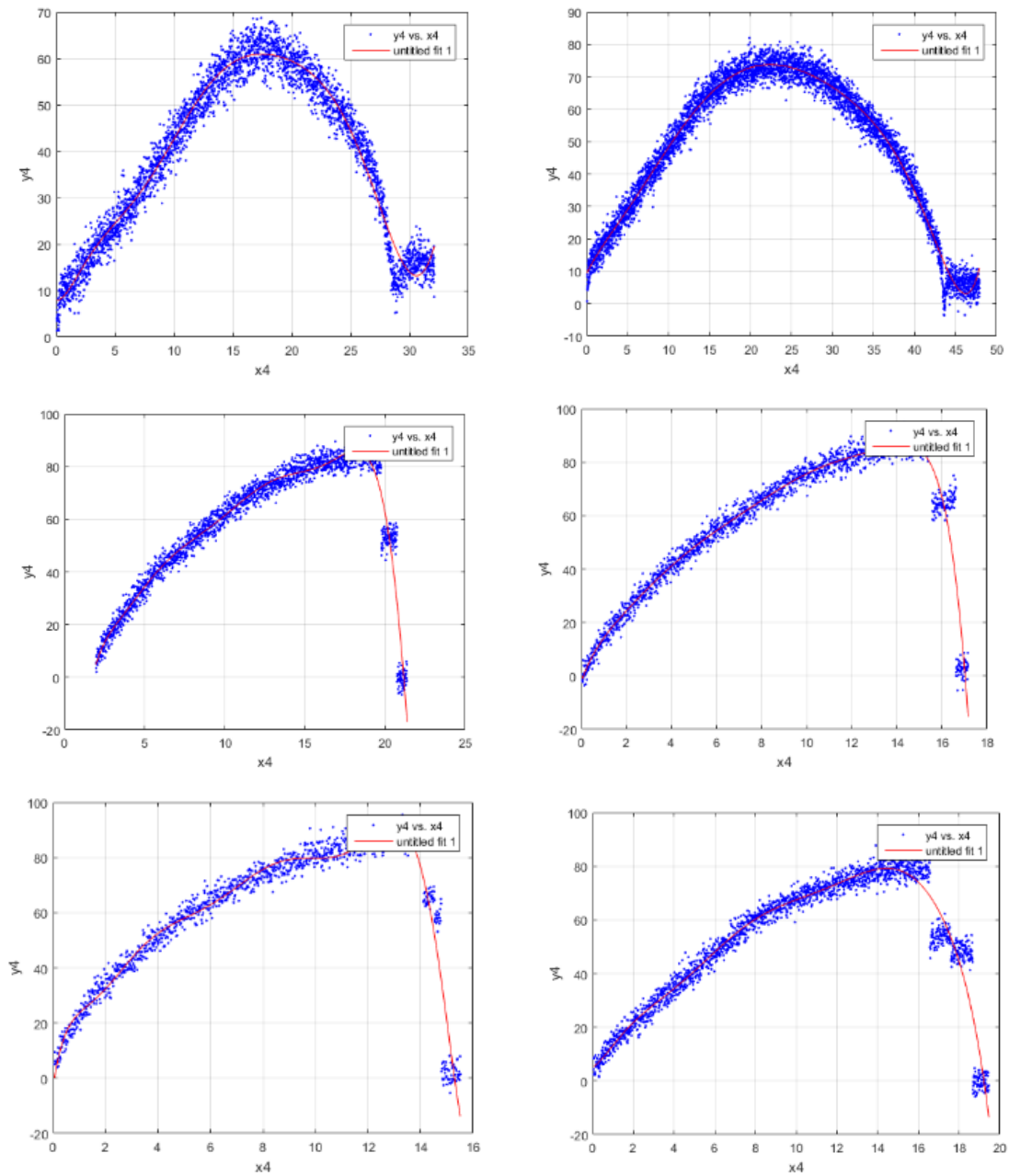
## 3.  Material Properties



**Figure 12**. Curve fit of Sample A from Tensile Test


Figure 12 and Figure 13 shows the curve fit with Deformation on X-axis as x4 and Load on Y-axis as y4 for Sample A and Sample B respectively and Modulus of elasticity are calculated as 5558 Pa for Sample A and 1575 Pa for Sample B.
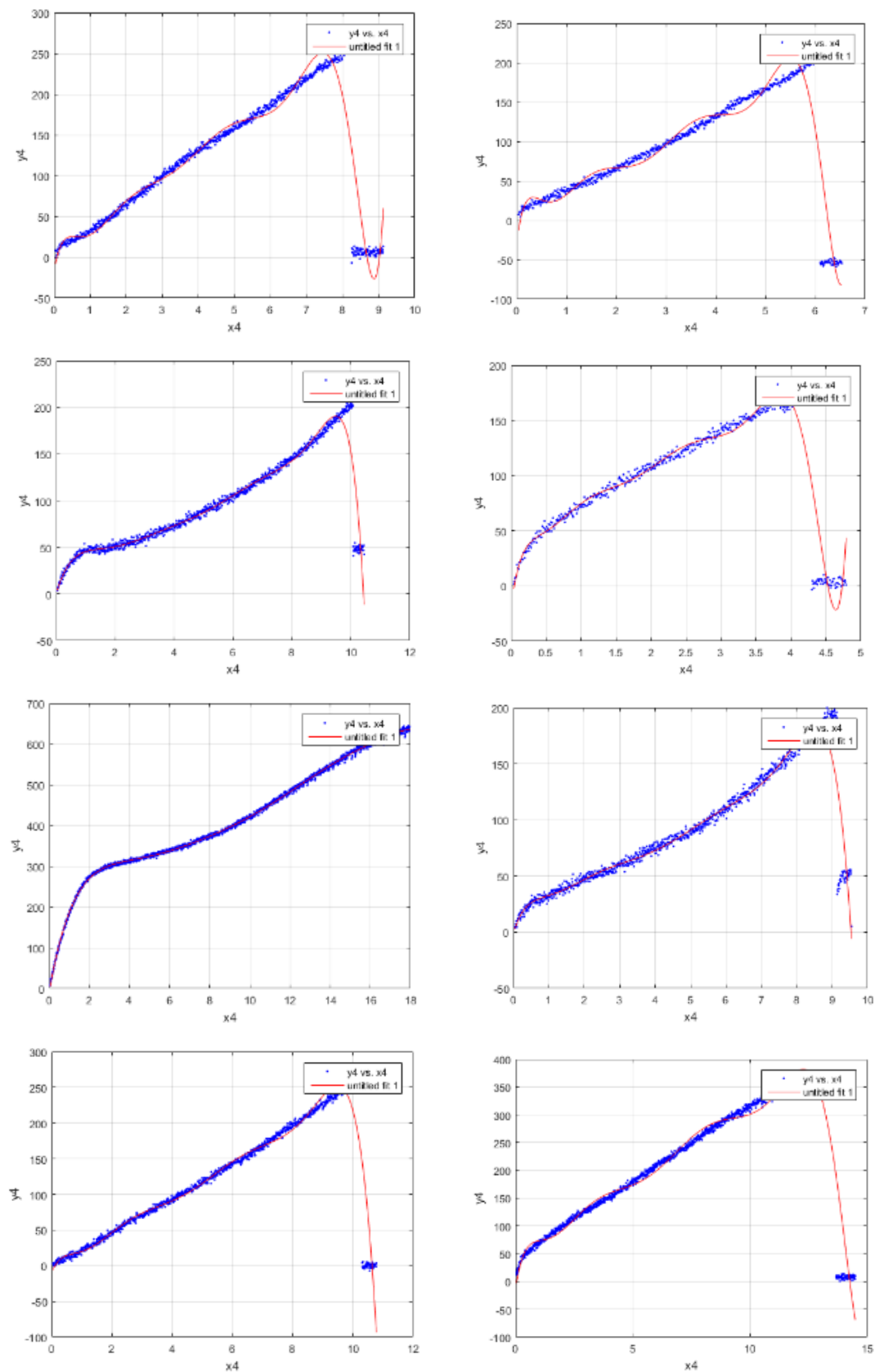
**Figure 13**. Curve fit of Sample B from Tensile Test

## 4. Analytical Modeling

As the sabot and projectile move towards the exit of barrel along the taper section, the sabot gets crushed by the catcher. The level of material crushed depends on the material of sabot.
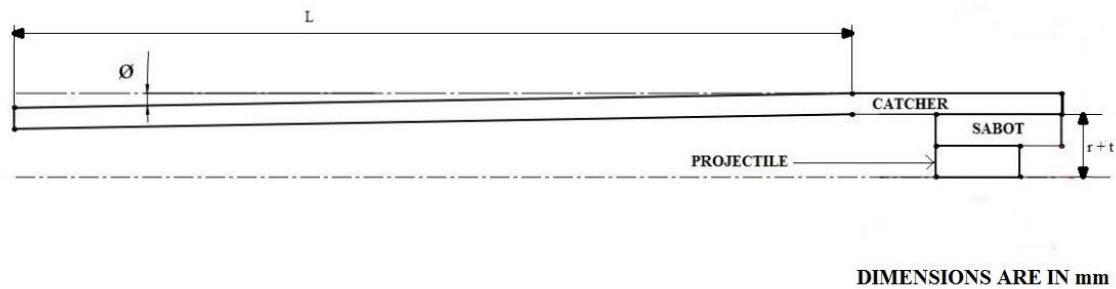


**Figure 14.** Cross Section of the catcher, sabot and projectile system

The position where the sabot stops is calculated by energy balance. The kinetic energy of sabot is,

$$KE = \frac{1}{2}mv^2 \tag{1}$$

If the sabot has stopped, the kinetic energy is converted into strain energy. Let the distance at which it stops be 'x' from start of taper section. By equating with equation (1) we get,

$$\frac{1}{2}(nwx^2 tan\emptyset)\sigma(x)\varepsilon(x) = \frac{1}{2}mv^2 \tag{2}$$

From equation (2), the value of 'x' can be calculated by giving values to other variables from design and material parameters.

## 5. Numerical Simulation

In catcher, sabot and projectile assembly as in Figure 15, the projectile is 60 mm long and has a diameter of 30 mm. The sabot is 80 mm long with 60 mm outer diameter[2]. The catcher has 6 beams of 11.2 mm wide and equispaced axisymmetrically, with a taper angle of 1°.
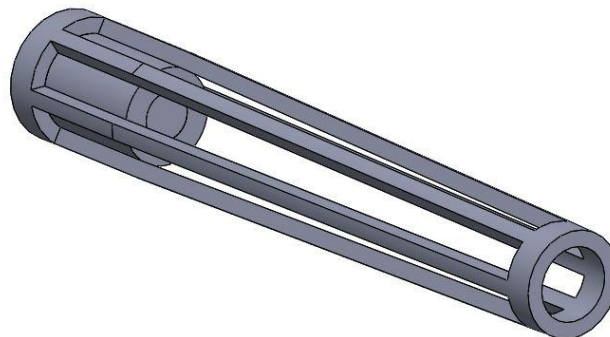


**Figure 15.** Catcher, Sabot and Projectile Assembly

The numerical analysis is performed to calculate the value of 'x', in equation (2). The analysis is performed in ANSYS Workbench, Explicit Dynamics Module. In this, the catcher is assumed to be non-deformable and completely fixed. The initial velocity of the sabot and projectile is taken as 250

m/s. The analysis is performed to calculate the value of 'x' for 2 different materials for sabot. The material properties of sabot are taken from the material testing performed on PU rigid foam of two samples A and B.

*5.1 Sabot of Sample A*
The Figure 16 shows the total deformation plot of whole setup with Sample A as material given to sabot. In this case, the sabot has moved a distance of 185.76 mm from the start of taper section.
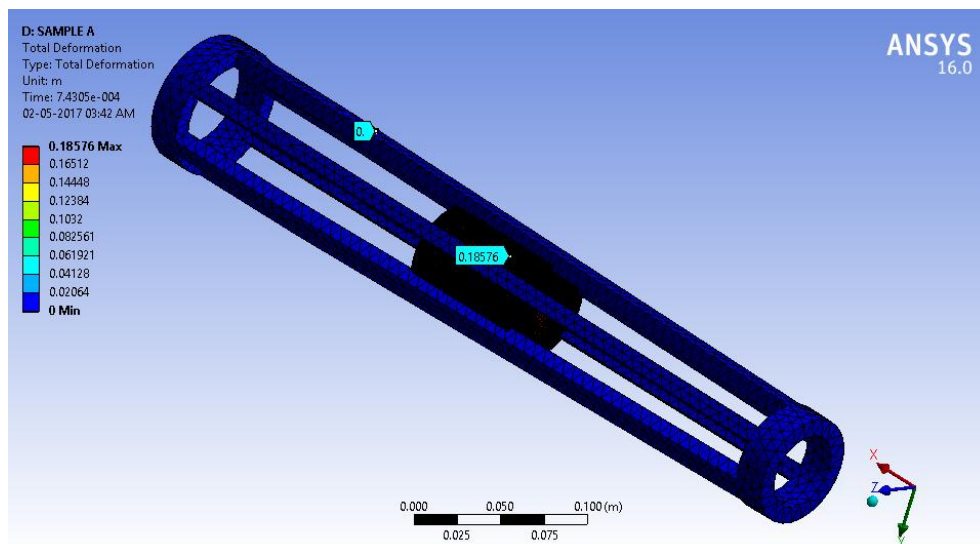


**Figure 16.** Total Deformation - Sample A

The sabot has moved a distance of 185.76 mm in a time interval of 0.743 m-s. During this process, the sabot material is crushed 3.242 mm radially by the catcher beams. This crushing of sabot is shown in Figure 17 as a detailed view.
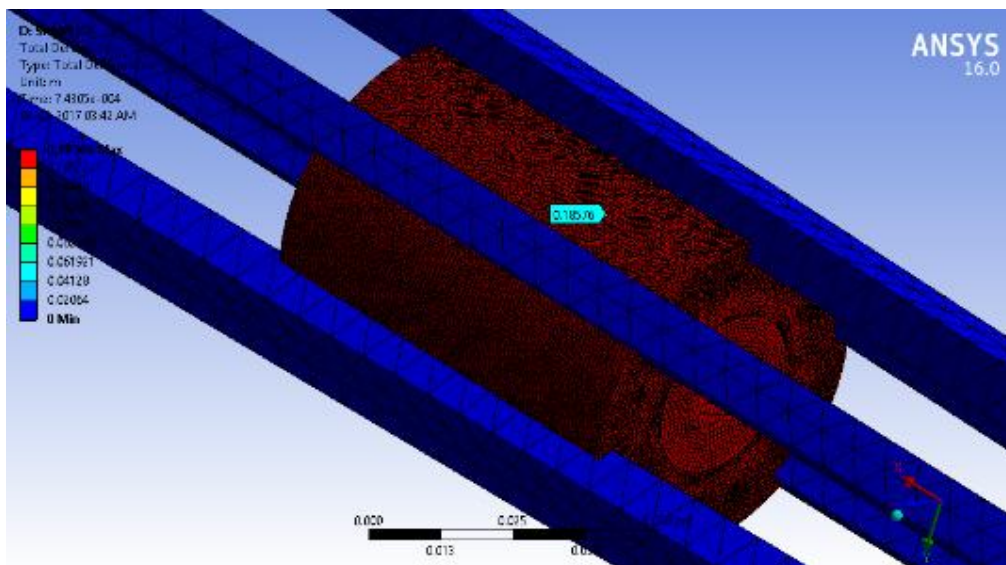


**Figure 17.** Sabot Crushing - Sample A

*5.2 Sabot of Sample B*

The Figure 18 shows the total deformation plot of whole setup with Sample B as material given to sabot. The sabot has moved a distance of 18.889 mm from the start of taper section.
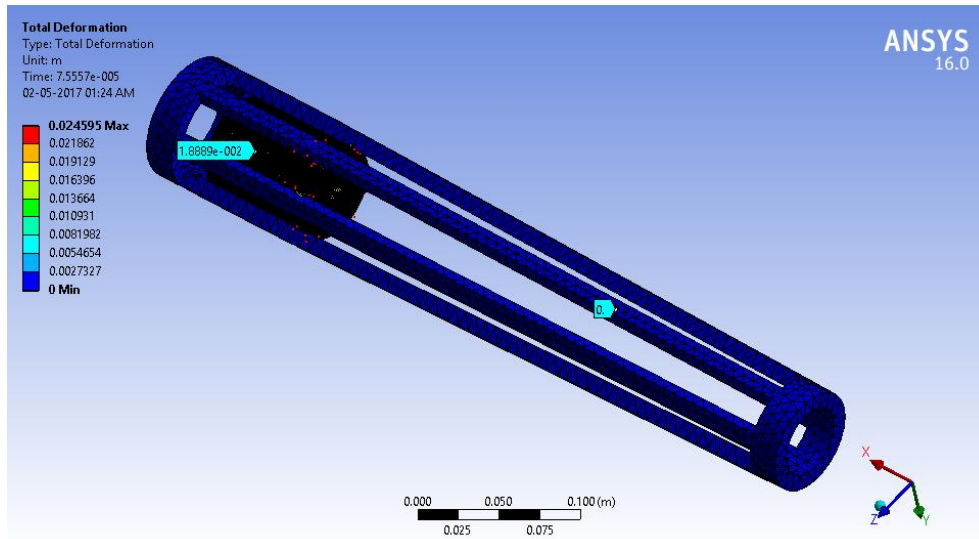


**Figure 18.** Total Deformation - Sample B

The sabot has moved a distance of 18.889 mm in a time interval of 75.557 µ-s. During this process, the sabot material is crushed 0.32965 mm radially by the catcher beams. This crushing of sabot is shown in Figure 19 as a detailed view.
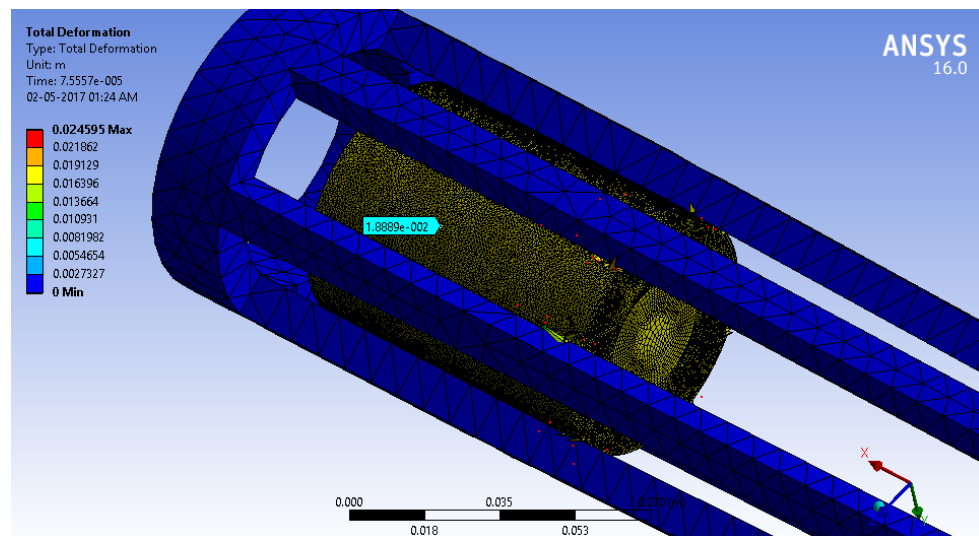


**Figure 19.** Sabot Crushing - Sample B

By comparing the above cases, the difference in distance covered by the sabot is very high. The distance covered by the Sample B is very less and the control of path in pitch and yaw motions of projectile is very less when compared to Sample A. PU Rigid Foam material has to be chosen very carefully for better results. If the distance covered by sabot is very high, then the exit velocity of the projectile will be very less, but stability and accuracy of the projectile can be high. On the other side, if the high exit velocity is needed, the distance covered by sabot should also be less. But, stability and accuracy will be less. So there is some compromise between the speed and accuracy we need. So by proper optimization, perfect design of a single piece sabot can be achieved.

## 6. Conclusion

In this study, two samples of PU Rigid Foam with different densities are taken and tested for its material properties by the standards. These obtained material properties are then used in Numerical Simulation of the Sabot-Catcher system. This simulation is carried out to conclude that the stopping distance of the sabot made of Sample A is higher than Sample B, which means the accuracy of the projectile is high with sabot of Sample A. But, the exit velocity will be reduced. So, by further research using different densities of PU Rigid Foams, the best suitable material can be obtained with required exit velocity and less loss in accuracy.

## 7. References

1. Charters A.C., 1987, *Development of the high-velocity gas dynamics gun*, International Journal of Impact Testing, vol. 5, pp 181-203
2. Koka T. R. and Mathew A. T., 2017, *Design of Sabot & Catcher of Single Stage Gas Gun for Bird and Hailstone Impact test*, International Conference on Materials Manufacturing and Modelling
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4. Pellegrino A., Tagarielli V. L., *et al*, 2015, *The Mechanical Response of a Syntactic Polyurethane Foam at a low and high strain rates*, International Journal of Impact Engineering, 75, pp 214-221
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