# An Experimental Validation on Mechanical Damages Caused by Air Cannon Projectile

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**Abstract.** The main objective of this paper is to study the damages caused by mechanical shocks for different materials and compare between the expiremental and simulation results. The study is based on series of experiments conducted on test bench that has been modified to comply with the experiments. Wherein, many equipment have been designed and manufactured in the laboratory. The shocks are created by Air Canon with different pressure values. The obtained results have provided a conclusive remarks about the shape and dimension of the damages with consideration of the material, speed, and angle of the shock.

**Keywords:** Damages · Mechanical shocks · Materials · Experiments · Air canon · Simulation of the experiment

## 1 Introduction

For a very long time, man has been content with a direct and simple exploitation of materials made available by nature, scientific and technological progress has significantly changed this approach [1]. Whether for sports, medicine, automotive industry, clothing or even electronic components, materials play a preponderant role today [2]. Therefore, all engineering disciplines have to understand the materials, even the most intangible like computer sciences or systems engineering depend on the development of new materials [3, 4]. The study of materials is very varied since it covers many fields like polymers, ceramics, metals and alloys, optical and electronic materials, composites or living materials [5, 6]. For each of them, it is a question of grasping the structures of matter on a microscopic or even atomic scale in order to understand its macroscopic properties. The engineers can then shape the material to give it some specific properties based on the desired performances and with consideration to materials limits and the change caused by their behavior in use [7, 8]. From other side, materials damage is almost always an unwanted event and can be in many cases catastrophic [9, 10]. Damage appearance in a material is caused by wear of physical or chemical attack; it leads to a deterioration of his physical capacities which could lead to rupture. Mastery of damage mechanism is a promising tool for describing the degradation of materials in order to predict the initiation and progression of deterioration in the structures [11, 12].


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A damage level can be directly related to physical properties if it is characterized by observable changes like micro-deformations, increased density of dislocations, surface degradation, microcracks, cavities, corrosion,…etc. All these phenomena are observable but sometimes they are difficult to be highlighted and they do not always help in defining the damages [13, 14]. Hence, understanding how materials behave and why they differ in properties are crucial questions. Modern materials science is the practice and experience-based science [15]. With modern computer technology, the progress made by the numerical simulation and prediction methods it is important to create and verify the simulation tools for the materials study by comparative studies between experiment and simulation [16, 17]. For that reason, this study is dedicated to design a test bench which allows the study materials damages behavior due to mechanical shocks. This test bench is designed by a laboratory team, and we have designed some parts of it. The bench allows us to make mechanical shocks against plates of different materials caused by a projectile launched by air cannon. The manuscript is organized as follows: In section two, different component of the test bench are described and different calculations for manufacturing some part of the device are given in order to allow reader understand the experiments. While the experiments realized in this study have been explained and the obtained results were discussed in section three. Flowed by a simulation conducted by ANSYS in section four. This study is up with conclusion and recommendations.

## 2 Test Bench

### 2.1 Air Cannon Principale

The experimental equipments used generally in ballistic tests are either the explosive generators or the guns [18]. The advantage of the gun compared to other methods lies in the detailed knowledge of the created shock, this is essential when it comes to achieving physics experiments requiring great precision [19]. On the other hand, the range of pressure accessible by explosive is very limited. A light air cannon is a test device consisting of a tank containing air under pressure connected to a compressor as soon as the desired pressure is reached the air is quickly released using a valve, the air then launches the projectile at high speed with certain acceleration to leaves the tube and crash into a sample to test its resistance.

### 2.2 The Test Bench Components

This study starts with finalizing an existing test bench; First, the test bench has been analyzed and the role of each component was identified. Second, faulty and missing test bench elements are recognized and a list of needs with the missing components was created. Third, the faulty elements were repaired and the missing components were provided. Fourth, solutions have been proposed to overcome the disadvantages of the test bench and improve test bench performance [20]. The components of the test bench are divided into two categories: components that have been adapted and installed in the test bench and components that have been manufactured in the laboratory of Mechanics at the National Polytechnic School of Algiers [21].

### 2.2.1 Independent Components

These equipments do exist in the laboratory, and they have adapted in order to be used for the experiments, they include: compressor, Air tank, electric valve, and flexible tube as shown in Fig. 1.


**Fig. 1.** Independent components of the test bench: a) Compressor, b) Air Tank, c) Electrical valve, d) Flexible tube

### 2.2.2 Manufactured Components

In this part, all missing equipments of the test bench have been manufactures in the laboratory, this parts of the test bench are constructed based on international norms, and they include the following equipments.

- The Projectile Launch Tube

This tube has an interior diameter of 10.8 mm and a length of 900 mm, it has a somewhat special shape as illustrated in Fig. 2. This tube is connected at its end where the nipples to the projectile launch tube hold. The metal supports design is shown in Fig. 3, it is used to avoid buckling due to the weight of the projectile launch tube.

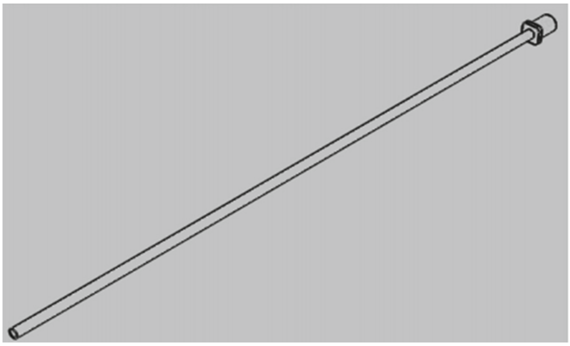


**Fig. 2.** Projectile launch tube: solidworks design

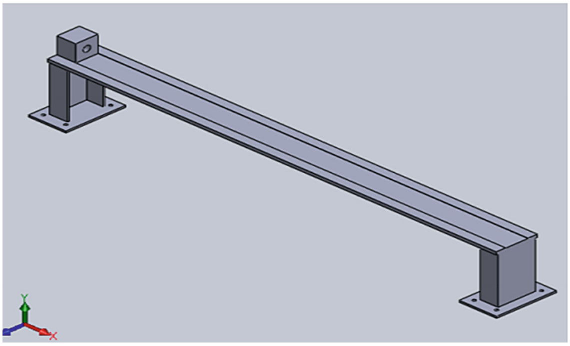


**Fig. 3.** Design of Support for the projectile launch tube

- Target Holder And Projectiles' Recovery

The target support plays a very important role because it allows defining the distance between the barrel exit and the target. Also, it can define the nature of the shock (normal or oblique). These parameters were used to enrich the designed experiments using this test bench (Fig. 4). Wherein, the target support mobility is ensured by a sliding system and the frame rotation is around its center.

### 2.3 Projectile Trajectory Verification

The dimensions of our target and the projectile catcher need to be defined in a way that the projectile crashes into the sample exactly in the middle. So to determine the impact position and ensure that the effect of gravity is negligible on the trajectory and the speed of the projectiles over the distance between the tube outlet and the sample, we conducted a small experiments and adapt our sample support position. The experiments consists in firing projectiles at targets placed at different positions. The results show that whatever the position is, the projectile penetrates the target at the desired point. The penetration point coordinates were recorded and from these coordinated, we built our target support ilustarted in Fig. 4.

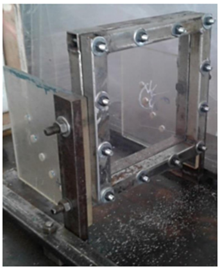


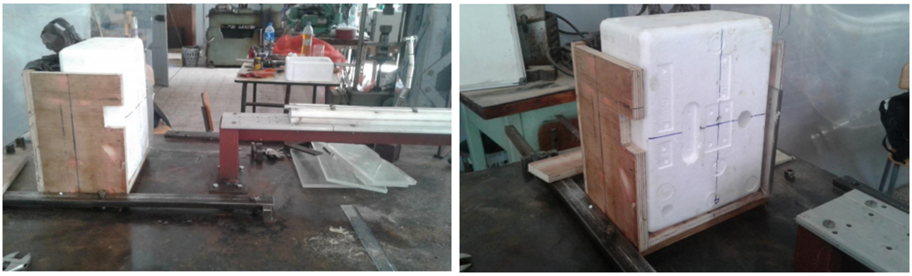
**Fig. 4.** Sample holder: manufactured equipment

- The penetration at 200 mm from the barrel outlet Fig. 5

(a) (b)

**Fig. 5.** Test bench for 200 m experiment: **a)** The projectile recuperator, **b)** The penetration position

- The penetration at 400 mm from the barrel outlet Fig. 6



(a) (b)

**Fig. 6.** The Test bench for 400 m experiment: **a)** The projectile recuperator, **b)** The penetration position

- The penetration at 600 mm from the barrel outlet Fig. 7

(a) (b)

**Fig. 7.** The Test bench for 600 m experiment: **a)** The projectile recuperator, **b)** The penetration position

## 2.4 Improvments

As a part of the contribution in this study, we have proposed some improvements on the design of the test bench, among these modifications the following solutions are discussed in the next subsections.

### 2.4.1 Solution to Recover Projectiles

Instead of filling the projectile recovery with polystyrene, it is better to use BETAGEL to provide shock absorption even at high speed and protect the shape of projectiles. BETAGEL, a Japanese invention, is a gel material and made of silicone capable of absorbing strong shocks. It has been shown that a plate of 300 mm$^2$ de BETAGEL was able to absorb the fall of an egg dropped from a height of 22 m without breaking.

#### 2.4.2 Solution to Capture Projectile Speed

To capture the speed, and follow the trajectory and why not observe the penetration of test tubes, we proposed the use of a high performance camera. The air canon is capable of sending the projectile with speed 200 m/s, then at least and for tracking the projectile trajectory with one step of 40 mm it is necessary to capture an image by $5 \times 10^4$ s. So, we needed a camera with a performance of 5000 fps.

## 3 Experiment

### 3.1 Preliminary Test

In order to avoid any unpredicted phenomena that may happen in the test bench during experiments, a series of preliminary tests have been conducted. These tests also allowed us to ensure the good functioning of all test bench components, and have an idea on the magnitude and speed of the shock so that security of human will be guaranteed.

### 3.2 Tests On Plexi Glass

The tests were carried out on plexi glass samples for pressure value of 2 bar. The first set of were on pieces perpendicular to the axis of the barrel and for the second set the pieces were tilted at 60°. All the test pieces were penetrated with different shapes cavities. Each figure represents the cavity observed on the impact side.

- **First series of tests:**

  For the shock of test sample perpendicularly $\theta = 0°$ Fig. 8

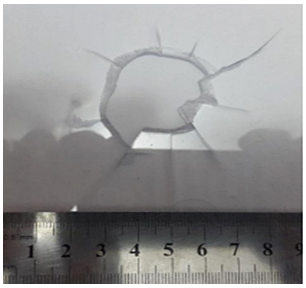



**Fig. 8.** The penetrated sample 1

For oblique shock at $\theta = 60°$ Fig. 9

**Fig. 9.** The penetrated sample 2

- **The second series of tests**

  For the shock of test sample perpendicularly $\theta = 0°$ Fig. 10

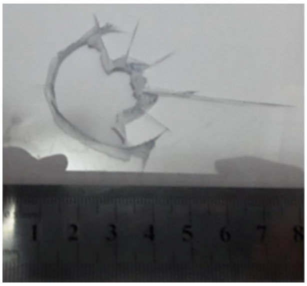


**Fig. 10.** The penetrated sample 3

For oblique shock at $\theta = 60°$: Fig. 11

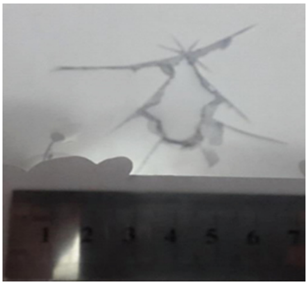


**Fig. 11.** The penetrated sample 4

After the analysis and observation of the damage measurement results and the photos of the damaged test tubes, it is noticed that the tilted sample have less damages than the sample exposed to perpendicular shock; the basic parameters necessary for understanding the behavior of materials subjected to intense shocks are not always directly accessible to the measurement. Therefore, the damage parameter that can be adopted is the peripheral surface, this surface gives an estimate of the energy of decohesion. Projectile – sample impact has leaded to crater formation on the impact face with a surface which is torn off from the sample. The material can be assumed to be fragile elastic upon impact zone. This peripheral surface can represent the energy of decohesion and quantify the damage. After observing the test samples, we have measured the damage by the conventional method, we set an observation area of 6,400 $mm^2$ and we obtained the results presented in Table 1.

**Table 1.** Measured damages of the test samples

| | | Damage D (mm) | |
|---|---|---|---|
| Check nature | Pressure (Bar) | First test series | Second test series |
| Normal shock (0°) | 2 | 0.031 | 0.045 |
| Oblique shock (60°) | | 0.002 | 0.003 |

## 4 Simulation Results

The computer simulation method and prediction have become more and more widely used technique in materials science research due to its advantage in reduce development costs and shorten the development cycle and one of this numerical simulation method is the finite element method. Which is a numerical way to solve some of the physics problems, it can permit to determine an approximate solution on a spatial domain, the method consists of cutting the spatial domain into small elements, also called meshes, and to seek a simplified formulation of the problem on each element, that is to say to transform the system of any equation into a system of linear equations. Each system of linear equations can be represented by a matrix. The systems of equations for all the elements are then brought together, which forms a large matrix; the resolution of this global system gives the approximate solution to the problem.

Ps. Known the projectile speed it is easy to deduce its acceleration thus the impact force used in our simulation.

- Simulation of the perpendicularly shock $\theta = 0°$ Fig. 12

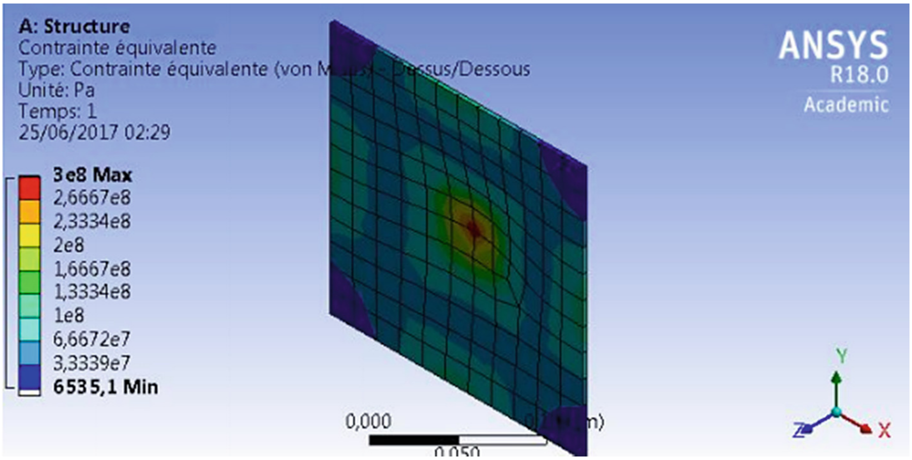



**Fig. 12.** Von Mises Stress on a normal shock of 2000 N

- Simulation of the oblique shock $\theta = 0°$ Fig. 13

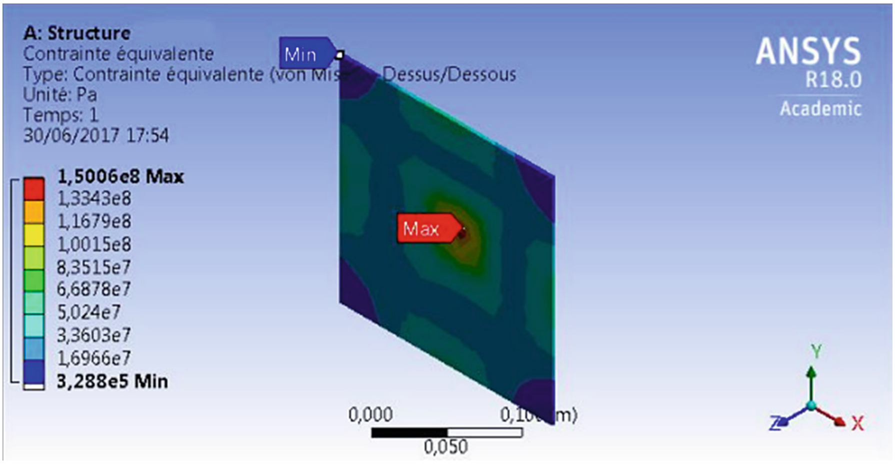



**Fig. 13.** Von Mises Stress for an oblique shock of 2000 N

The observation of results obtained for the equivalent stress of Von shows that the equivalent stress is much greater than the resistance of the material at the center of the test sample. Knowing the elasto-fragile behavior of the material, the impact causes a rupture by decohesion without creation of plastic deformation which confirm the conclusions in the experimental part.

## 5 Conclusion

Developments of materials can offer real solutions to the issues of smart cities that are built around the world, from utilising resources in the best way, to creating more efficient applications, to finding new applications for widely available elements. Recent examples include the development of lightweight for aerospace or automotive to reduce energy consumption and advancing miniaturization, as well as continuing breakthroughs being made in self-healing materials. Without materials developments it will become increasingly difficult to build truly smart cities. Getting to this point requires innovation in materials by identifying their properties therefore the objective of this study was to model and understand the damages in a test bench on different materials using air cannon. The Materials damage is a complex phenomenon involving a large number of mechanisms, the modified test bench was designed to do experiments by using projectiles launched by air cannon, it is applied on samples with 200 $mm^2$ surface. Moreover, in order to quantify the damage, shots with 2 bars pressure were taken for perpendicular and inclined samples. The obtained results permitted us to quantify the damages. It was concluded that the predominant factors during the tests was the speed of the projectile. A simulation study has been realized in order to check its reliability comparing to real experimental results. The good match between numerical and experimental conclusions has validated our proposed approach and the reliability of modifications in the test bench. As recommendations, a reliable speed sensor must be added to the test bench in order to obtain the most desired bench's performance.

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