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Research Article

Development Of Small Shock Tube For Dıaphragm Integratıon Studıes

Dr D Raja Joseph[1], A. Rahul[2], K. Harsha Vardan[3], K. Naga Kishore[4], N. Bhargav Reddy[5]

Abstract

The shock tube is a laboratory instrument used to generate shock waves under controlled conditions, it is a tool for experimental investigation of shock wave phenomena. It is a simple and inexpensive experimental setup that can be designed and developed for research and to study about shock waves. Basically, the shock tube has two sections, one is high pressure section called driver section and another one is low pressure section called driven section. The two sections were separated by a diaphragm.

The purpose of developing this small shock tube is “By investigating the probability and trends of shock wave Mach number that was observed while using a combination (or) integration of various diaphragm objects in a small shock tube”. In this experiment we used Tracing paper (Tp) of 95 GSM, Bond paper (Bp) of 75 GSM, Regular A4 paper (Rp) of 70 GSM, Aluminium foil (Al) of 0.2 mm thickness.

This work focuses on design and development of an experimental set up of shock tube to perform a detailed study on the effect of change of shock wave and Mach number for each and every material and its layered position in the integrations of diaphragm.

Keywords: *Stainless Steel Driver & Driven section, Shock tube, Diaphragm, Integration of Diaphragms, Bursting Pressure, Shockwave Mach number*

[1] Dept of Aeronautical Sciences, Hindustan Institute of Technology & Science, Chennai, India.
[2] Dept of Aeronautical Sciences, Hindustan Institute of Technology & Science, Chennai, India.
[3] Dept of Aeronautical Sciences, Hindustan Institute of Technology & Science, Chennai, India. harsha.kolluru23@gmail.com
[4] Dept of Aeronautical Sciences, Hindustan Institute of Technology & Science, Chennai, India.
[5] Dept of Aeronautical Sciences, Hindustan Institute of Technology & Science, Chennai, India.

Introduction

The shock wave is a thin region of flow where it creates a quick change in the state of the fluid. The shock waves propagate fluid properties like pressure, velocity, and temperature. The flow of a shock wave satisfies the conditions of balance for mass, energy, and momentum. Entering these conditions gives the results for a normal unsteady shock wave in a perfect gas. The pressure, density, temperature, and velocity jump across the shock wave as well as the Mach number of the flow behind the shock.

$$\frac{P_2}{P_1} = 1 + \frac{2\gamma}{\gamma+1}\left(M_S^2 - 1\right) \tag{1}$$

$$\frac{\rho_2}{\rho_1} = \frac{M_S^2}{1 + \frac{\gamma-1}{\gamma+1}(M_S^2 - 1)} \tag{2}$$

$$\frac{T_2}{T_1} = 1 + \frac{2(\gamma-1)}{(\gamma+1)^2}\frac{(M_S^2 - 1)(1 + \gamma M_S^2)}{M_S^2} \tag{3}$$

$$\frac{\Delta w}{a_1} = -\frac{2}{\gamma+1}\frac{M_S^2 - 1}{M_S} \tag{4}$$

$$M_2^2 = \frac{1 + \frac{\gamma-1}{\gamma+1}(M_S^2 - 1)}{1 + \frac{2\gamma}{\gamma+1}(M_S^2 - 1)} \tag{5}$$

Where P1 is the pressure before the shock wave and P2 is the pressure after the shock wave. Ms is the Mach number of the shock wave, γ is the specific heat ratio of gas, $a1 = \sqrt{\gamma RT1}$ is the speed of the sound, $2 = \sqrt{\gamma RT2}$, Δw is the flow velocity difference across the shock wave, and M2 is the Mach number behind the shock wave. The Mach numbers Ms and M2 are defined as $Ms = \frac{w1}{a1}$ and $2 = \frac{w2}{a2}$.

1.1 THE SHOCK TUBE EQUATION

The shock tube is given by the pressure ratio of the driver section P4, and driven section P1. The driven section with pressure P1, speed of the sound in it is ‘a1’, and specific heat ratio is ‘γ1’. The driven section is with pressure P4, speed of the sound in it is ‘a4’, and specific heat ratio is ‘γ4’. The shock wave generates in the driven section. And the shock wave disturbs the molecules from stage 1 to stage 2. At the same time the formation of expansion wave changes the fluid state from state 4 to state 3. State 2 resembles to shock-proceeding fluid, and state 3 resembles to expansion of the fluid after creating an expansion wave.

$$\frac{P_4}{P_1} = \frac{1 + \frac{2\gamma_1}{\gamma_1+1}(M_S^2 - 1)}{\left(1 - \frac{\gamma_4-1}{\gamma_1+1}\frac{a_1}{a_4}\frac{M_S^2-1}{M_S}\right)^{\frac{2\gamma_4}{\gamma_4-1}}}$$

Therefore, the Mach number ‘Ms’ can be found by the pressure in both sections and by the speed of sound and by the specific heat of the fluid

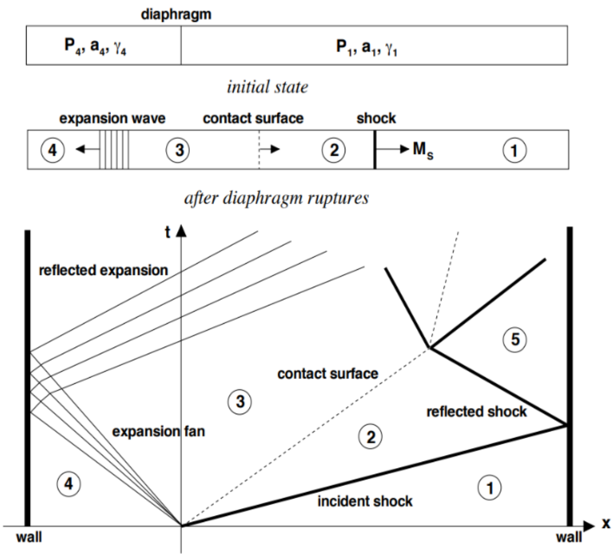


Fig1.13: Shock tube experiment and Shock wave diagram

Material Selection

The material selected for the fabrication of the Shock tube is Stainless steel for the following properties: -

1. High yield strength
2. Corrosive resistance
3. High strength at high temperatures
4. High tensile strength
5. Good cryogenic resistance
6. Ease of fabrication
7. Aesthetic appearance

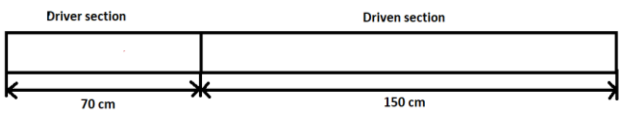
The material is chosen such that it should satisfy analysis results and operations as well. We have chosen “Stainless Steel” instead of Mild Steel because of their properties, cost, volume, corrosive resistance, maintenance etc. Stainless steel has high strength and it is corrosive resistant, so inside the tube it is smooth when compared to Mild Steel, therefore in Stainless Steel there won’t be any disturbance for the flow of shock wave.

Computational Analysis

3.1 INTRODUCTION

ANSYS R16 software is used for analyzing the various designs of mounting structure. It is a complete FEA simulation software package developed by ANSYS Inc. – USA.

There are various analysis methods available in ANSYS software. We have selected the 2D CFD analysis method, because it is the basic method and it determines the 2D flow inside the shock tube, temperature, pressure, and speed of the shock wave inside the shock tube.



GOVERNING EQUATIONS

The standard set of 3D fluid equations are

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{u}) = 0 \quad (1)$$

$$\frac{\partial (\rho \vec{u})}{\partial t} + \nabla \cdot [\vec{u}(\rho \vec{u})] + \nabla p + \nabla \cdot \vec{T} = 0 \quad (2)$$

$$\frac{\partial (\rho E)}{\partial t} + \nabla \cdot [E(\rho \vec{u})] + \nabla \cdot (\rho \vec{u}) + \nabla \cdot (\vec{T} \cdot \vec{u}) + \nabla \cdot \vec{j} = 0 \quad (3)$$

where ρ is the mass density, −→u the flow speed, E the total energy density (E = e + u2/2, e is the internal energy density), −→T is the stress tensor and →j the heat flux. Eq. (1) is the conservation of mass, Eq. (2) is the conservation of momentum and Eq. (3) is the conservation of energy. The shock tube problem analysed in this project considers inviscid flows (viscosity is null) and adiabatic processes. The governing equations in this case reduce to the classic fluid equations, where there is no stress tensor and no heat flux.

The equations to be solved are:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{u}) = 0 \quad (4)$$

$$\frac{\partial (\rho \vec{u})}{\partial t} + \nabla \cdot [\vec{u}(\rho \vec{u})] = 0 \quad (5)$$

$$\frac{\partial (\rho E)}{\partial t} + \nabla \cdot [E(\rho \vec{u})] + \nabla \cdot (\rho \vec{u}) = 0 \quad (6)$$

3.2 GEOMENTRY AND MESH

First, we added the 2D design which is done in the CATIA software. we give boundary conditions to the 2D design. Next, we gave Face Meshing to the 2D design with 0.5 mm spacing.

1. No. of Nodes = 176142
2. No. of Elements = 173580

The inflations of 4mm are given to the walls near to before and after the diaphragm. To get the

Detailed flow visualization of waves generated after the rupturing of diaphragm.

3.3 INITIAL AND BOUNDARY CONDITIONS

The initial and boundary conditions are described in the files p, T and u in the folder 0 of the solver. We assumed a uniform internal field of null velocity everywhere and a nonuniform internal field for pressure and temperature. Like represented in Figure 4.1, the driver section has pressure of 100,000 Pa and temperature of 341 K, while the driven section has pressure of 100,000 Pa and temperature of 341 K. The temperature values are obtained from the ideal gas law, considering Sod's initial conditions in section 1. The solver rho Central Foam, in fact, requires initial and boundary conditions for the T field rather than the density one. All the boundary walls are set to have zero gradient and the walls are kept as "empty". In general, we given density based and steady iterations. And we gave 25,000 iterations for each test we did.

3.4 ANALYSIS

3.4.1 Analysis -3 Bar Pressure

The analysis for 3 bar input pressure in driver section is carried using ANSYS R16 software. The following initial conditions are considered.

- Initial pressure in both sections - 100,000 Pa
- Initial temperature - 341 K
- Flow of fluid - Inviscid flow

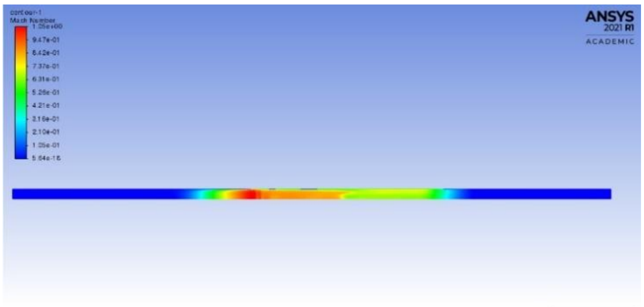


Fig3.1 Flow visualization in a shock tube at 3 bar input pressure

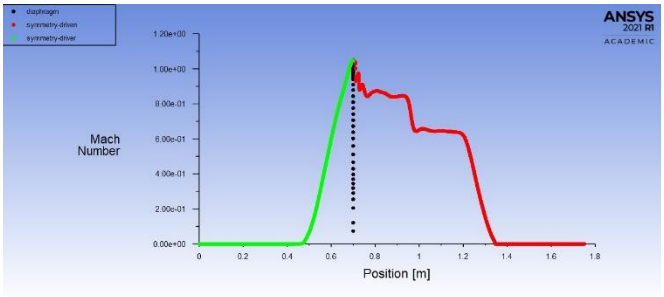


Fig 3.2 Mach number graph for 3 bar input pressure

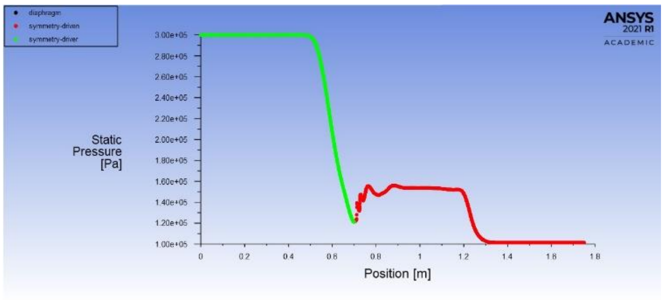


Fig3.3 Pressure graph for 3 bar input pressure

3.4.2 ANALYSIS – 4 Bar pressure

The analysis for 4 bar input pressure in driver section is carried using ANSYS R16 software. The following initial conditions are considered.

- Initial pressure in both sections - 100,000 Pa
- Initial temperature - 341 K
- Flow of fluid - Inviscid flow

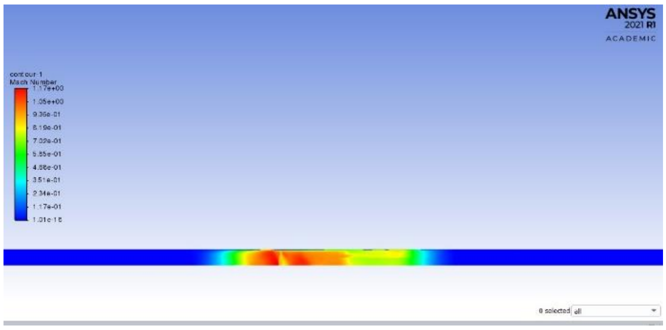


Fig 3.4 Flow visualization in a shock tube at 4 bar input pressure

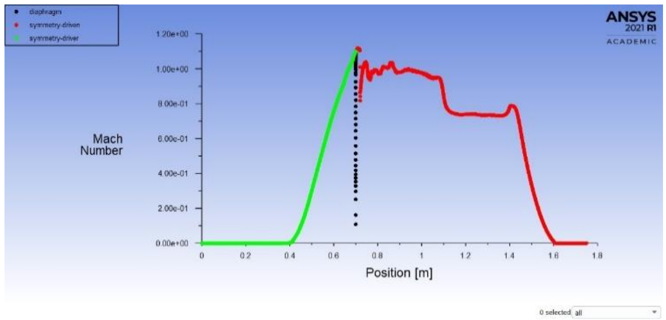


Fig.3.5 Mach number graph for 4 bar input pressure

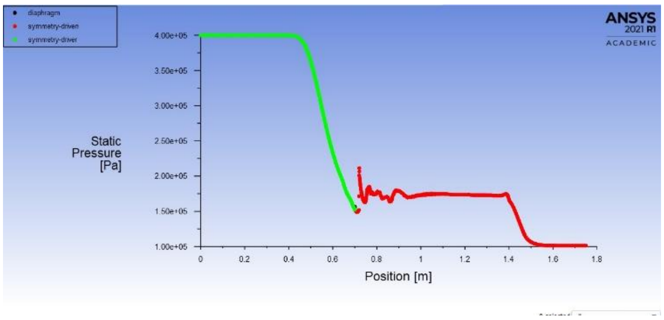


Fig3.6 Pressure graph for 4 bar input pressure

3.4.3 ANALYSIS – 5 Bar Pressure

The analysis for 5 bar input pressure in driver section is carried using ANSYS R16 software. The following initial conditions are considered.

- Initial pressure in both sections - 100,000 Pa
- Initial temperature - 341 K
- Flow of fluid - Inviscid flow

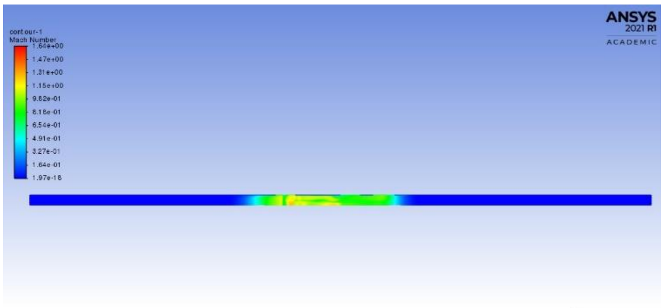


Fig 3.7 Flow visualization in a shock tube at 5 bar input pressure

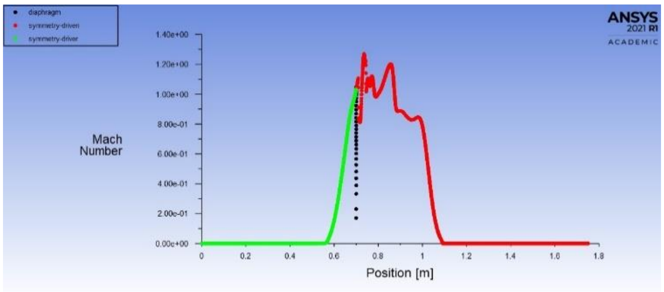


Fig 3.8. Mach number graph for 5 bar input pressure

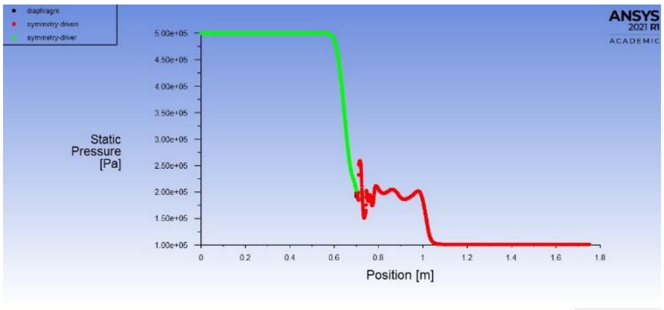


Fig 3.9 Pressure graph for 5 bar input pressure

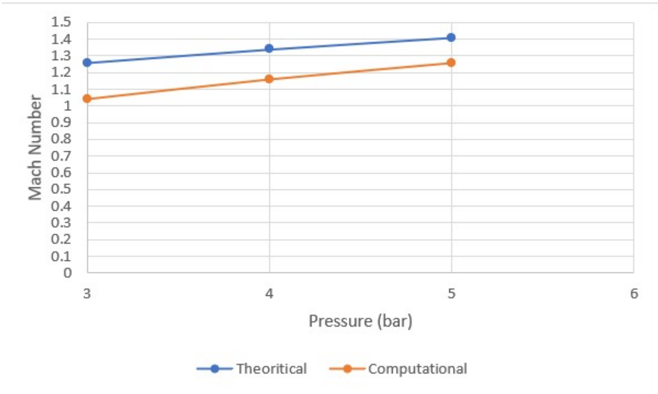


Fig 3.10. Theoretical & Computational Pressure Vs Mach Number Graph

ANALYSIS	PRESSURE (bar)	MACH NUMBER (M)
1	3	1.04
2	4	1.16
3	5	1.27

Desıgn And Development

4.1 Development of a small shock tube for diaphragm integration studies

The literature survey conducted initially showed that the diaphragm bursting pressures were in the range of 2 bar to 6 bar. So, a shock tube which can withstand a maximum pressure of 10bar is designed and suitable materials were found to be Stainless-Steel, Mild Steel, Aluminium, and etc.

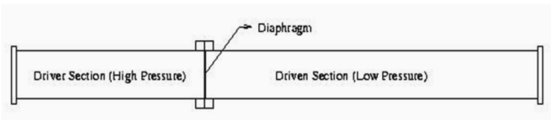


Figure 1: A schematic diagram of a conventional shock tube

Fig 4.1 Schematic diagram of a Shoc tube

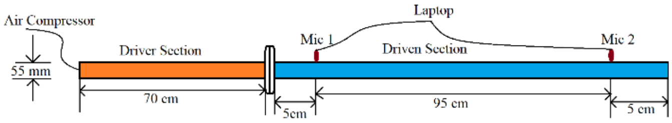


Fig4.2 . Schematic Diagram of the Setup.

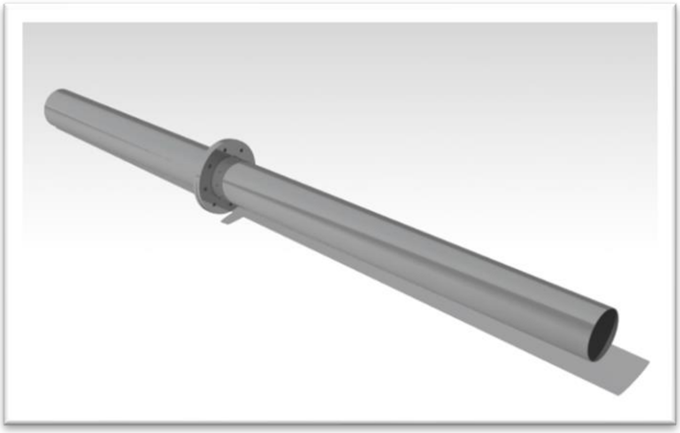


Fig 4.3 Design of the Shock tube made in Solid works.

Fig 4.4 Experimental Setup

Testing And Implementation

5.1. Single layer of Tracing paper. (Tp)

A single layer of tracing paper is selected as diaphragm material in test 1. Tracing paper being a little bit porous nature. It was found that the bursting pressure out to be 1.6 bar. Which produced a speed of 311.475 m/s wave, which was not enough to produce a Shock wave. When calculated to Mach number it was found to be produced0.913.

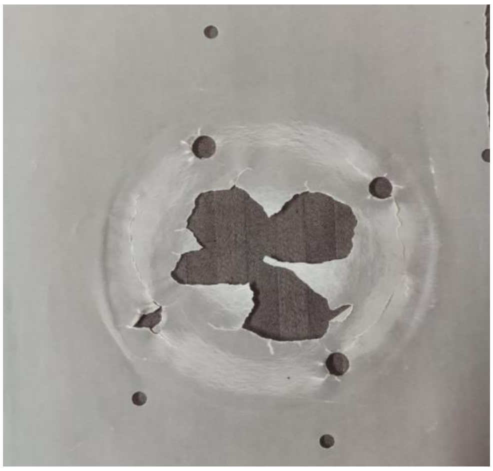


Fig.5.1. Test 1- Single Layer of Tracing paper

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5.2. Two layers of Tracing paper. (Tp-Tp)

In test 2, two layers of Tracing paper is taken as Diaphragm material. The pressure valve is opened, and the bursting pressure is 1.9 bar. Speed of the shock wave is found to be 375.49 m/s. Which when calculated to Mach it was found to be producing 1.04. So, it was equal to the speed of sound.

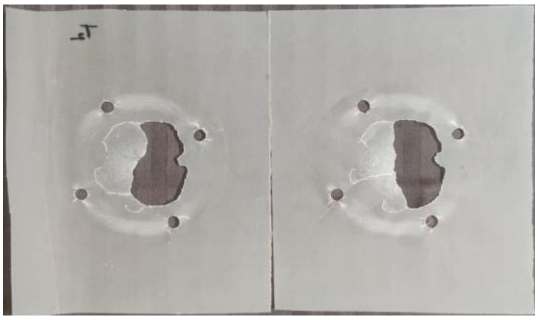

Fig.5.2. Test 2 -Two layers of Tracing paper.

5.3 Tracing paper- Aluminium Foil – Tracing paper. (Tp-Al-Tp)

In the third trial three layers are used of two different materials. The first layer was tracing paper, second was Aluminium foil, third was again tracing paper. Aluminium foil is no porous material. The bursting pressure is 3.2 bar. And the speed of the shock wave produced is 433.789 m/s. When calculated for the Mach Number it was found out to be 1.27. Which is enough to produce a shock wave. So, from this layer onwards shock wave is produced.

Fig. 5.3. Test 3- Al - Tp- Al

5.4. Aluminium Foil -Tracing Paper-Aluminium foil (Al-Tp-Al)

In trial 4 we have selected the inverse of the previous selection which is two layers of Aluminium Foil and one layer of Tracing paper. The bursting pressure is 3.4 bar. The speed of the shock wave produced was 452.380 m/s. The calculated Mach number is 1.36. again, producing a Shock wave.

Fig 5.4. Test 4 -Al- Tp-Al

5.5. Aluminium Foil-Bond paper –Aluminium Paper (Al-Bp-Al).

In test 5 we have used Aluminium foil- Bond Paper- Aluminium foil as our diaphragm materials. The explosive pressure of this diaphragm materials is found to be 2.4 bar. The speed of the shock wave produced is 394.190 m/s. The calculated Mach number of this 1.21. producing a shock wave.

Fig 5.5. Test 5- Al-Bp-Al

5.6. Tracing paper- Regular Paper-Bond Paper- Tracing Paper.

S.No	Bursting Pressure	Time Delay	Mach (Exp)	Theoretical Calculations
T1	1.6	0.00305	0.916	1.12
T2	1.9	0.00253	1.04	1.21
T3	3.2	0.00219	1.27	1.29
T4	3.4	0.00210	1.36	146
T5	2.4	0.00241	1.21	1.52
T6	4.4	0.00200	1.40	1.52
T7	3.8	0.00209	1.32	1.42

Test 6 consisted of 3 different materials of 4-layer combinations of the sequence Tracing paper- Regular A4 sheet paper- Bond Paper- Tracing Paper. All the materials in this combination are porous materials. The bursting pressure in this combination is found to be the highest of 4.4 bar. The speed of the shock wave produced is 475 M/s. The calculated Mach number is also found to be the highest 1.4.

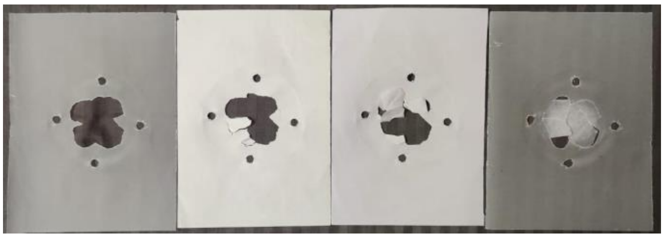

Fig. 5.6. Test 6 – Tp-Rp- Bp-Tp

5.7. Aluminium foil - Tracing paper - Tracing Paper - Tracing Paper- Aluminium Foil. (Al- Tp-Tp -Al).

In the seventh test that we have conducted. The combination is of two materials comprising of 4 layers of i.e., Aluminium foil 2 layers and Tracing Paper 2 layers. The bursting pressure is found to be in this integration, which is 3.85 bar. The speed of the shock wave produced 454.545 m/s. The calculated Mach number in this combination of 1.32.

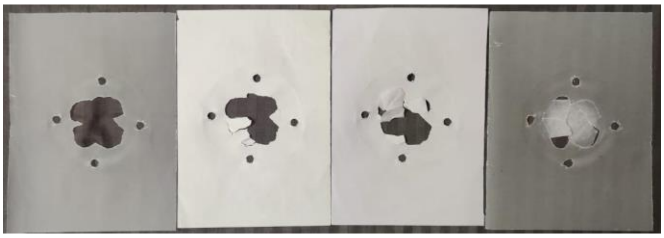

Fig5.7. Test 7 Al-Tp-Tp-Al

Tab 5.1 Experimental Bursting Pressure and Mach Number produced

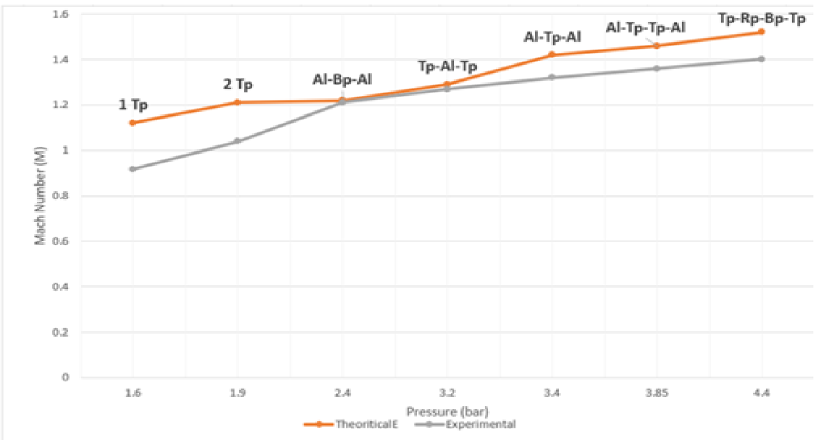

Fig 5.8. Pressure vs Experimental and Theoretical Mach number produced

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