Environment. Technology. Resources. Rezekne, Latvia
Proceedings of the 15th International Scientific and Practical Conference. Volume III, 268-273

Designing a laboratory stand for testing impact resistance of plastic films by free-falling dart drop according ASTM D1709

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Abstract. **In this article, the process of designing a laboratory stand for testing impact resistance of plastic films using free-falling dart drop method according to ASTM D1709, type A will be followed. It will be analyzed the all stages of designing-synthesis of project solutions, analysis and optimization, assessment and presentation of tasks. The purpose of the article is to create a designing basis for the variable design of impact resistance stands to be used in the design of non-standardized laboratory equipment.**

Keywords: dart drop impact test, plastc films, CAD/CAE, ASTM 1709, properties of plastics

I. Introduction

Impact resistance refers to dynamic mechanical tests and is characterized by the destruction of test specimens with a high speed of loading (impact)[1]. When testing impact resistance internal defects, position of the part in relation to the load, notches, etc [2]., are important. Impact resistance is a complex characteristic because it includes plastic and strength characteristics [3].For now, there is no known relationship between impact toughness and other mechanical parameters. An analogy of the results with different shapes and materials is not possible.

The wide application of a variety of polymers in modern engineering requires study of their main mechanical characteristics - hardness, strength and plastic characteristics, impact resistance [4]. Impact resistance of polymers and composites are mainly done by dart drop methods [5],[6].[7].

Due to the specificity of the dart drop impact test - the impossibility of using results for parts of other sizes, shapes and materials, the use of non-standard laboratory equipment is required in practice for the study of impact resistance. For the purpose of the article, the design of a stand according to the ASTM 1709 standard was chosen, but the stages of design-synthesis of design solutions, analysis and optimization, and evaluation may be easily adapted to other needs and specifications.

II. Materials and Methods

In the test standard ASTM D1709, the materials for the incremental weights are defined - brass or stainless steel and aluminum alloy for the hemispherical head of the dart drop.

For the purposes of the article, the following materials were chosen – a constructive steel for pressing discs, for the hemispherical head of the dart drop-aluminum alloy 6082, for the details of the stand and the adjacent equipment stainless steel AISI 304.

Aluminum alloy 6082 is distinguished by excellent anti-corrosion properties and good machinability [8]. The choice of stainless steel 304 is due to the high strength, durability, corrosion resistance and good workability by cutting[9]. Its good physical and mechanical properties make it a preferred material for industrial equipment and for specific laboratory stands.

The design includes 5 main stages, fig. 1, which will be discussed.

Print ISSN 1691-5402
Online ISSN 2256-070X
https://doi.org/10.17770/etr2024vol3.8139

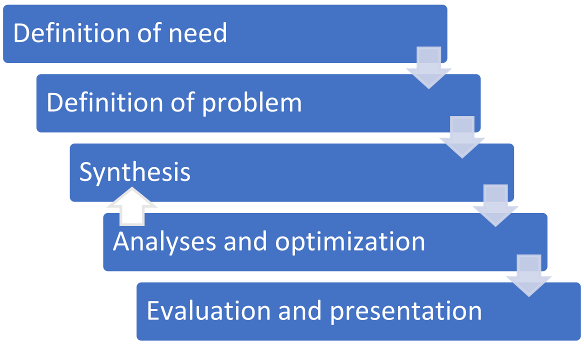

Fig. 1. Stages of designing

Determination the needs - on the one hand, only standardized dart drop stands are available on the market, which greatly limits testing possibilities because of huge variety of materials and shapes.

On the other hand, dart drop tests have established itselves as an important part of the technical specifications of plastic films. This necessitates the use of non-standardized equipment or modular test machines.

Statement of the task includes a detailed description of the product to be designed. The goal is modular design of a laboratory stand according to ASTM D1709 and creation of a designing basis for variable design of non-standard dart drop equipment.

Synthesis of design solutions, design generally may be divided into design of the mechanical part, electrical part, pneumatic part. The schematic diagram of the laboratory bench is shown in Fig. 2, according to the ASTM D1709 standard.

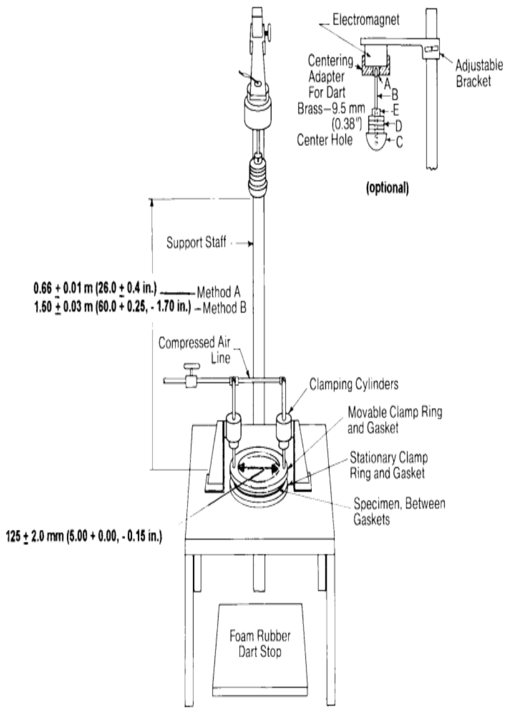

Fig. 2. Principle scheme of the stand, according the standard[10]

The dimensional analysis is integrated into the CAD environment, used in designing process [11]. The mechanical part can be divided into the following subsystems (modules):

- Housing
- Clamping mechanism for workpiece
- Dart dropgrip stand
- Dart drop

The housing of the impact resistance stand is the basic element and serves to establish the pneumatic and electrical subsystems of the assembled unit[12]. The standard does not define specific requirements for the housing of the stand. From a structural point of view, the body of the stand is of a prismatic type. A 3D model of the housing with adjacent holes for pneumatic and electrical components is shown in Fig.3

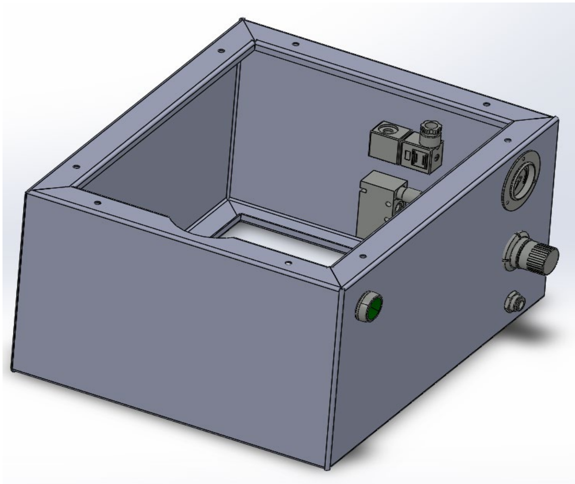

Fig. 3. 3D model of the housing

The clamping mechanism is the most important element of the stand and it should meet the following requirements[13],[14]:

- Clamps should have an internal diameter of 125 ±2 mm
- The lower clamp should be stationary
- The upper clamp should provide sufficient force to prevent slippage of the specimen, but also not to damage the specimen

A 3D model of the clamping mechanism is shown in fig. 4. The mechanism is pneumatically powered.

The dart drop grip stand has a height according to ASTM D1709 type A - 0.66 m ±0.01 m. It is designed to be disassembled so that another stand may be used at a later stage for another type of dart drop or similar impact test with a different height. The stand of the mechanism has the possibility of adjusting the position vertically and horizontally so that the impact is perpendicular to the sample and exactly in the centre of part,fig. 5.

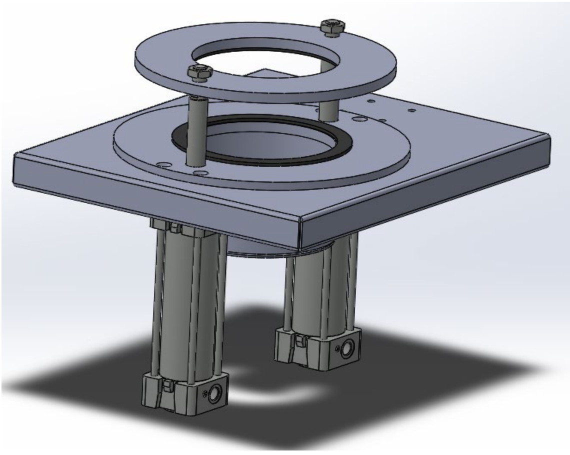

Fig. 4. Clamping mechanism

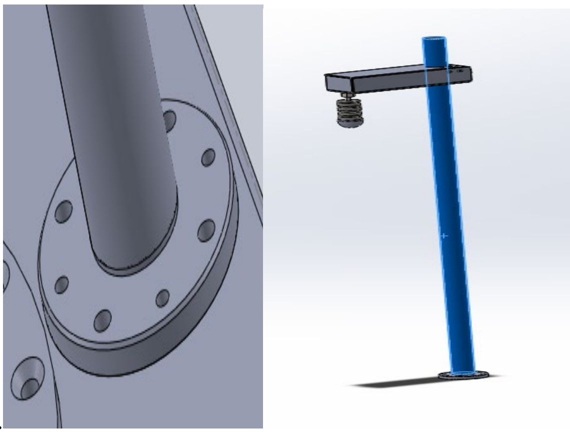

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Fig. 5. 3D model of the dart drop stand

The shaft of the dart drop is designed with sufficient height to allow for tests with weights up to 2 kg. The 3D model is shown in Fig. 6. The dart drop has a hemispherical head with a radius of 38 mm ±1 mm. The control is equipped with a timer with a time delay at start, which adjusts the time between pressing and releasing the dart drop.

Pneumatic subsystem:

The maximum force of the pneumatic cylinder was calculated. It depends on the pressure inside the cylinder, the diameter of the piston, the frictional force generated by the components[15].

The basic formula for calculating the power of an air cylinder is:

$$Ft = P \times Au = P \times \left(\frac{\pi}{4}\right) \times D^2 =$$

$$= 600000 \times 0{,}00125 = 754\,N .$$

where

Ft - Theoretical force [N] . It is theoretical, since the force of friction is neglected;

P - the pressure inside the cylinder [Pa]

Fig. 6. Au – Area of useful area in contact with air [m^2].

The stand is equipped with a manometer and a pressure regulator, with the help of which the pressing force is determined within the limits - 10 ÷ 754 N[16].

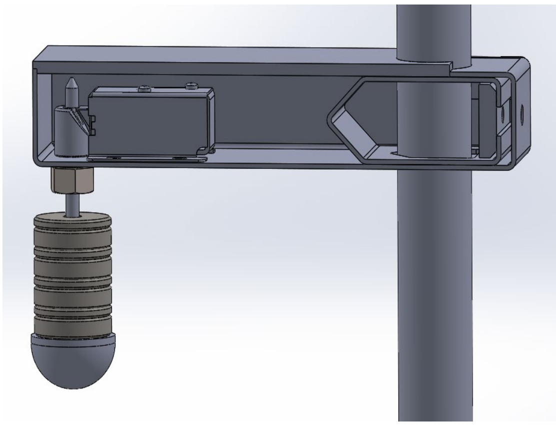

Fig. 7. Dart drop mechanism

The principle diagram of a trunk part is shown in Fig. 7:

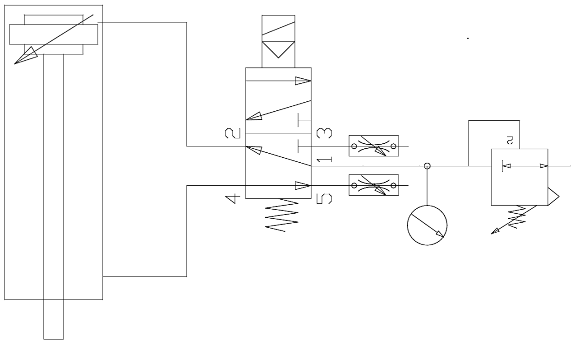

Fig. 8. Principle scheme of the pneumatic subsystem

Electrical subsystem:

The electrical part of the system is shown in fig. 8. It consists of power supply unit, fuses, buttons, timer, electro-pleumatic valve and electromagnet[17].

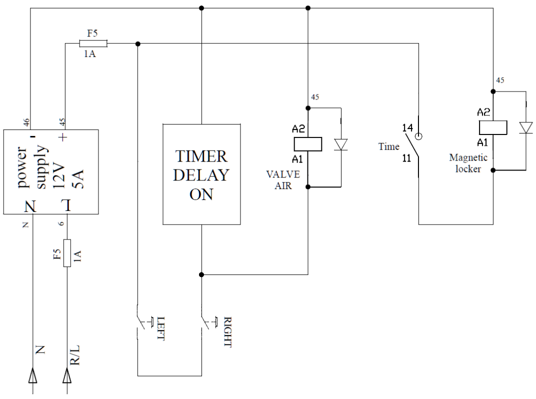

Fig. 9. Electrical scheme

The device is equipped with 2 buttons to start the test process. They are located at a sufficiently large distance from each other, as shown in Fig. 9 - position 47. This ensures the use of both hands of the operator and minimizes the possibility of injury. The entire operating installation, such as distributors, electromagnet and buttons, is performed on 12v..

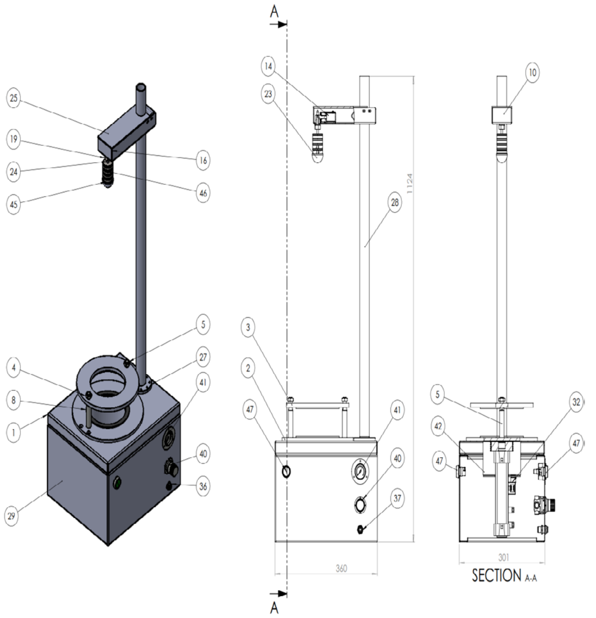

Fig. 10. Scheme of the stand

In fig. 10 shows the finished stand. Various materials were tested and the system worked effectively.

Fig. 11. The manufactured stand

III. Results and Discussion

Analyze and optimization

The dynamic analysis for behavior of the impact when testing a polyethylene sample was carried out using the CAE product ANSYS 19, Explicit dynamic module according to the following methodology [18],[19],[20]:

- Preparation of the 3D geometric model for testing and its import into ANSYS;
- Defining the material constants of the studied components;
- Generation of the discredited computational model based on the finite element method;
- Setting force load on the model;
- Introduction of boundary conditions;
- Selecting the parameters from the numerical results and defining the time of the experiment;
- Obtained results - graphically and tabularly. Table 1 shows data about impact testing. The standard height from which the wedge is released is 660mm. The specimen is made of polyethylene with a thickness of 100 µm pressed into the hoop as shown in fig. 12 The test temperature is not set to 22. °C.

TABLE 1 Description of the impact

Object Name	*Pre-Stress (None)*	*Drop Height*
State		Fully Defined
	Definition	
Pre-Stress Environment		None Available
Pressure Initialization	From Deformed State	
Input Type		Drop Height
Define By		Drop Height
Drop Height		660, mm
Impact Velocity		3597,9 mm/s
Coordinate System		Global Coordinate System
Direction		-Z Direction
Suppressed		No

In fig..11-13 are presented the data, generated by the program.

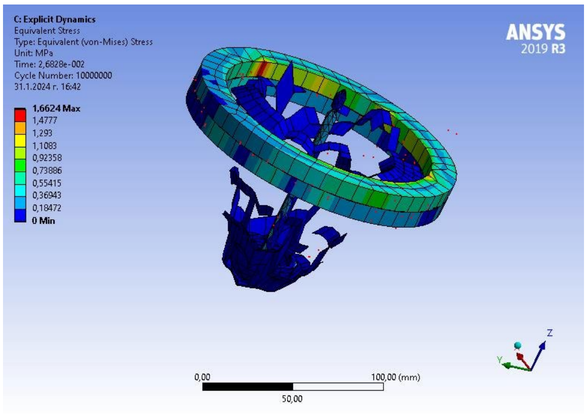

Fig. 12. Equivalent stress – von – Mises

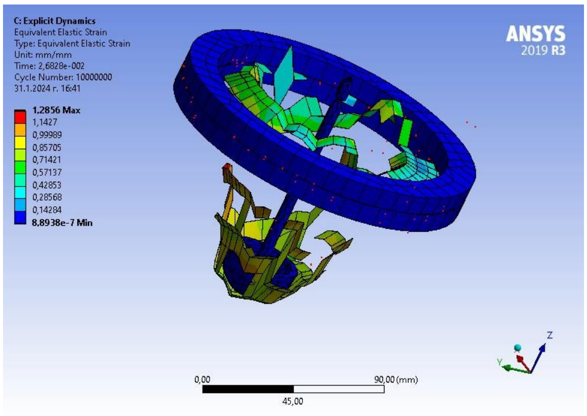

Fig. 13. Equivalent elastic strain

The purpose of the applied engineering analysis is to carry out a simulation of the impact test in order to select a combination between the thickness of the sample and the weight of the dart drop, for a selected material, which leads to a successful destructive testing. By using this CAE tool, a discrete test area is found more quickly and the total number of tests is reduced - resulting in material savings and faster results.

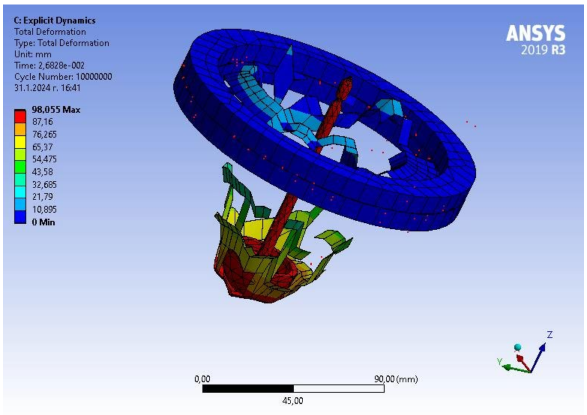

Fig. 14. Total deformation

In fig. 14 -15 the graphs of Equivalent Stress and Energy Probe are presented. The results obtained for Energy Probe are tabulated.

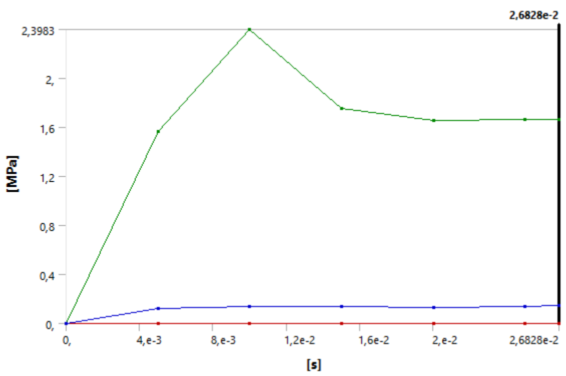

Fig. 15. Equivalent Stress

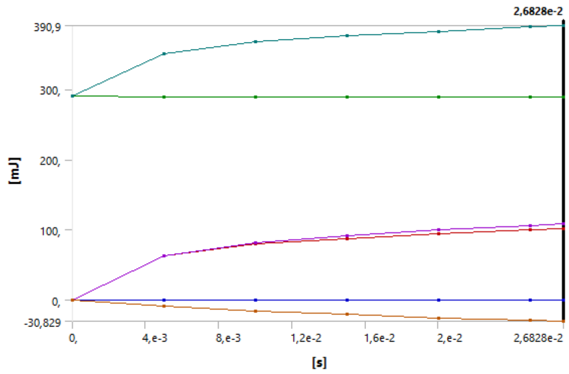

Fig. 16. Energy Probe

TABLE 2 ENERGY PROBE

Time [s]	Energy Probe (Internal) [mJ]	Energy Probe (Kinetic) [mJ]	Energy Probe (Plastic Work) [mJ]	Energy Probe (Hourglass) [mJ]	Energy Probe (Contact) [mJ]	Energy Probe (Total) [mJ]
1,18E-38	0	291,08	0	0	0	291,08
5,00E-03	61,762	289,38		63,102	-8,8894	351,14
1,00E-02	79,222	289,2		81,198	-16,444	368,43
1,50E-02	86,804	289,19		91,746	-20,948	375,99
2,00E-02	93,27	289,18		99,105	-25,919	382,45
2,50E-02	99,563	289,19		105,64	-29,764	388,75
2,68E-02	101,72			108	-30,829	390,9

TABLE 3 LOADS

Object Name	*Fixed Support*	*Force*
State	Fully Defined	
Scope		
Scoping Method	Geometry Selection	
Geometry	3 Faces	1 Face
Definition		
Type	Fixed Support	Force
Suppressed	No	
Define By		Vector
Magnitude		700, N (step applied)
Direction		Defined

The executed dynamic simulation with CAE shows, that the calculated theoretical pressure force is enough to prevent displacements of samples, which is significant condition for proper dart drop testing The simulation may be used as a part of engineering analyze for unstandardized stands. Due to the wide various of tested polymers, the executed simulation may be used as a tool to define the important parameters of the test-weight of the dart drop, distance between the dart drop and the sample. This will reduce the number of tested samples and will spare time and used material.

IV Conclusions

A stand for the impact resistance of plastic films was designed by the free-falling dart drop method fully satisfying the requirements of ASTM D1709 type A. All design stages were considered in order to variably design such equipment. The stand was tested with samples of different materials and showed no deviations beyond those defined in the standard. The design of laboratory equipment is an important practical engineering task because it provides the basis for individualized, standardized, and non-standardized designs [21]. The stand is equipped with a system for smoothly adjusting pressing force. A simulation was made in CAE to determine the discrete area for the test in order to reduce the number of trials.The weight of the dart drop is in the range of ±0,02g, which meets the standard requirements. The distance between the dart drop and the sample is according type A of the standard.

Acknowledgments

The author/s would like to thank the Research and Development Sector at the Technical University of Sofia for the financial support.

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