Artıbilim: Adana Alparslan Türkeş Bilim ve Teknoloji Üniversitesi Fen Bilimleri Dergisi 3(1), Haziran 2020, 25-33
Adana Alparslan Turkes Science and Technology University Journal of Science

Drop-weight impact behavior of paper under spherical impactors

Ahmet Refah Torun [*1], Furkan Nuri Karaoğlu[2], Şeyma Helin Kaya[3], Elif Kuşvuran[4], Naghdali Choupani[5]

[1]*Adana Bilim ve Teknoloji Üniversitesi,Havacılık ve Uzay Bilimleri Fakültesi ,Havacılık ve Uzay Mühendisliği, Adana*
[2]*Adana Bilim ve Teknoloji Üniversitesi,Fen Bilimleri Enstitüsü ,Nanoteknoloji ve Mühendislik Bilimleri Bölümü , Adana*
[3]*Adana Bilim ve Teknoloji Üniversitesi,Mühendislik Fakültesi ,Biyomühendislik , Adana*
[4]*Adana Bilim ve Teknoloji Üniversitesi,Mühendislik Fakültesi, Malzeme Mühendisliği, Adana*
[5]*Adana Bilim ve Teknoloji Üniversitesi,Mühendislik Fakültesi, Makine Mühendisliği, Adana*

Geliş Tarihi:10.07.2019 **Kabul Tarihi:**13.06.2020

Abstract

Paper yields non-linear and anisotropic mechanical properties which are difficult to determine. Its understanding of low velocity impact behavior is important for further applications such as punching and deformations during carrying. Commercial copy paper of 80g/m2 is widely used by the industry which is examined within this study. Steel balls with differing weights and diameters were used as drop weights. The effects of span area, number of paper layers and the impact position (edge effect) were experimentally determined.The increase of the free span area increases the energy absorption under impact through the enhanced spring effect of the paper material. As the position of the penetration approaches to the fixed edges, the energy absorption decreases. The highest energy absorption was observed around the center of the span area. The increase of the number of layers of paper almost linearly increases the energy absorption under impact.

Keywords: Drop-weight test, Impact resistance, Paper

Kağıdın bilya ile çarpma dayanımı etkisi altındaki davranışı

Özet

Kağıdın lineer olmayan ve anizotropik mekaniksel davranışından dolayı mekanik özelliklerini belirlemek zordur. Üretimden sonraki aşamalarda oluşabilecek deformasyonların anlaşılması için kağıdın düşük hızlı çarpma davranışının incelenmesi gerekmektedir. Bu çalışma kapsamında standart 80g/m^2'lik kağıdın çarpma dayanımı deneysel olarak araştırılmıştır. Düşme testlerinde farklı ağırlıklardaki çelik bilyalar kullanılmıştır. Kağıdın serbest çarpma yüzey alanı, katman sayısı ve çarpmanın gerçekleştiği yerin konumunun (kenar etkisi) çarpma dayanımına etkileri belirlenmiştir. Serbest yüzey alanındaki artışın yay etkisi yaratarak enerji emişini artırdığı gözlemlenmiştir. Bilyanın çarptığı nokta sabitlenmiş kenara yaklaştıkça enerji emişi düşmektedir. En yüksek enerji emişi kağıdın merkezinde görülmüştür. Kağıdın katman sayısının artması enerji emişini lineer olarak artırmaktadır.

Anahtar Kelimeler: Düşme testi, Çarpma dayanımı, Kağıt

[*]Sorumlu yazar (Corresponding author): Ahmet Refah Torun, artorun@atu.edu.tr

1. Introduction

Although the society and the office environment is being more and more digitalized, paper still remains as one of the most used consumables. The mechanical properties of the paper, which determines its performance during enduse, is highly dependent on the fibre reinforced anisotropic and non-linear structure of the sheet. Mechanical failures of paper such as wrinkling, cracking, splitting and web breaks are to be avoided commonly encountered phenomena. On the other hand, if the fracture toughness of the paper is adjusted too high, then the necessary further production steps of punching, binding, tearing becomes difficult in terms of tolerances and energy. There is no widely accepted standard method to determine the fracture of paper materials.

Fracture mechanics with both linear elastic and non-linear approaches have proved applicable to fracture of paper [1, 2]. However large samples are necessary for testing with accuracy which makes the linear approaches difficult to apply [3]. It is possible to accurately test the fracture toughness with non-linear approach and standard clamps [4]. Impact tests on paper materials are reported on honeycomb papers in the literature which are used by packaging industry [5,6]. No study has been reported on the impact tests of commercial copy papers.

This study aims to experimentally evaluate the impact behavior of copy paper through drop weight testing. The fracture of paper under impact loading was modelled with a commercial finite element analysis software. The testing and modeling methods presented will provide an easy to conduct procedure for professionals to determine the impact behavior of paper. As paper is a quasi uni-directional fibre reinforced material, there will also be implications on the study of impact behavior of fibre reinforced composites.

2. Materials and methods

Commercial copy paper of 80g/m2 and 0.1mm thickness was used during experiments. All samples were conditioned according to ISO 187 norm. The reinforcing fibers in the paper are oriented through the machine direction during the manufacturing process, therefore the strenght of the paper is higher in the machine direction in comparison with the cross direction. The results of tensile tests and fracture toughness in machine direction (MD) and cross-direction (CD) are taken from the literature (Mäkelä and Fellers 2012). All tests were performed under 65% relative humidity and 25^{o}C conditions. Drop weight impact tests were conducted with 4 different steel balls weights and diameters of: 4.2g – 10mm; 11.2g – 14mm; 43.7g – 22mm; 84.3g – 27.5mm. The sample papers are fixated between two frames from the edges. The geometries and dimensions are shown in Figure 1. Two square frame couples were used for testing the effects of span area and number of paper sample layers. Circular span frame was used to determine the edge effect. All frames were manufactured from sheet metal of 3mm thickness. The two layers of metal sheet frames hold the paper between them and the whole package is fixed with four clamps.

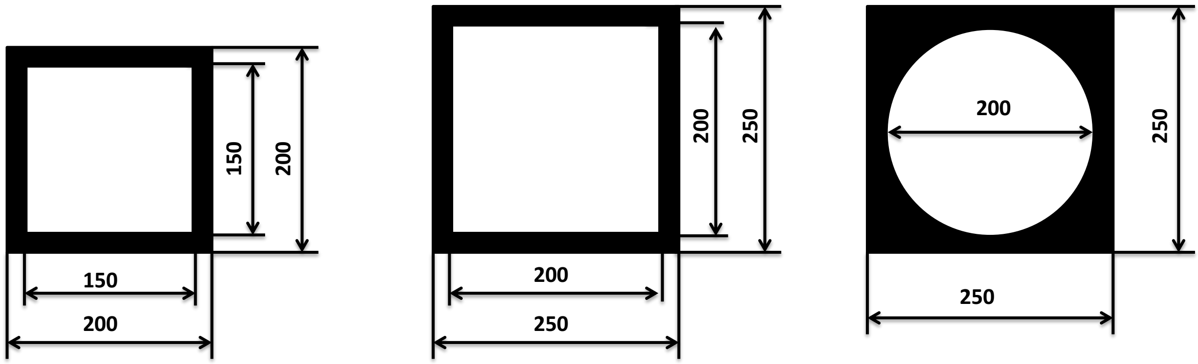

Figure 1. Dimensions (mm) of Frames Used in Drop Weight Tests

Steel balls were dropped from varying heights of maximum 240cm. Every sample or layer of samples were tested from stepwise increasing heights of 5cm. The damaged samples were replaced and the height of drop was increased until a full penetration was observed. Fracture on samples after the penetration was documented. Figure 2 demonstrates the experimental setup (Figure 2a) , the fractured paper surface after the impact test (Figure 2b) and the spherical impactors (Figure 2c). The spherical impactor was dropped from increasing levels to the surface of the paper. If the paper is not penetrated then a new paper is fixed and in the next step the impactor was dropped from 5 cm higher until the penetration occurs. If the height of the penetration for a particular impactor and paper is determined, then the maximum impact energy absorbed by the paper is the potential energy of the impactor (mgh) from the surface of the frame.

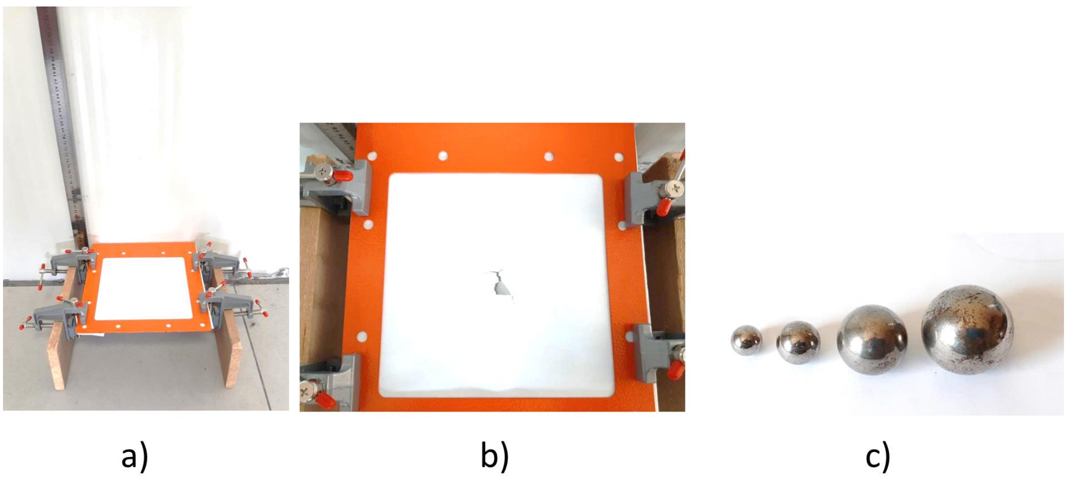

Figure 2. a) Experimental setup for the drop-weight impact test of the paper b) fracture of the paper surface after impact test c) spherical steel impactors 4.2 g, 11.2 g, 43.7 g and 84.3 g from left to right

3. Results and discussion

Steel balls of 4.2g, 11.2g and 43.7g were dropped onto the middle point of the surface of fixated paper samples. The square frame of 150mm x 150mm was used to hold the paper samples of 1-5 layers (Figure 1). Figure 3 demonstrates the results of the drop tests, which consist of the minimum energy value for a full penetration through the paper layer(s). Increasing weight and diameter of steel balls led to a higher energy absorption.

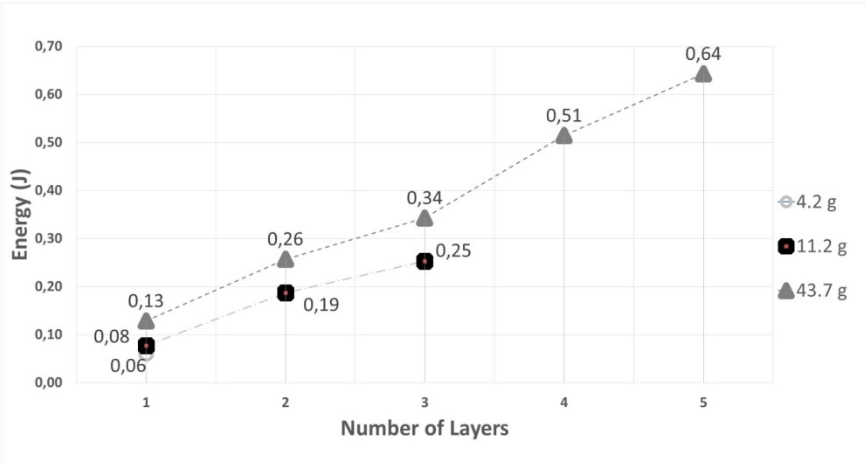

Figure 3. 15x15cm square target span – effect of layers and ball weight

In order to see the effect of a larger target span area, steel balls of 4.2g, 11.2g and 43.7g were dropped onto the middle point of the surface of fixated single layer paper samples with an increased span of 200mm x 200mm square frame (Figure 1). Two layer sample was tested only with 43.7g steel ball to see the tendency of energy absorption of more than one layer. Figure 4 shows the results of drop tests.

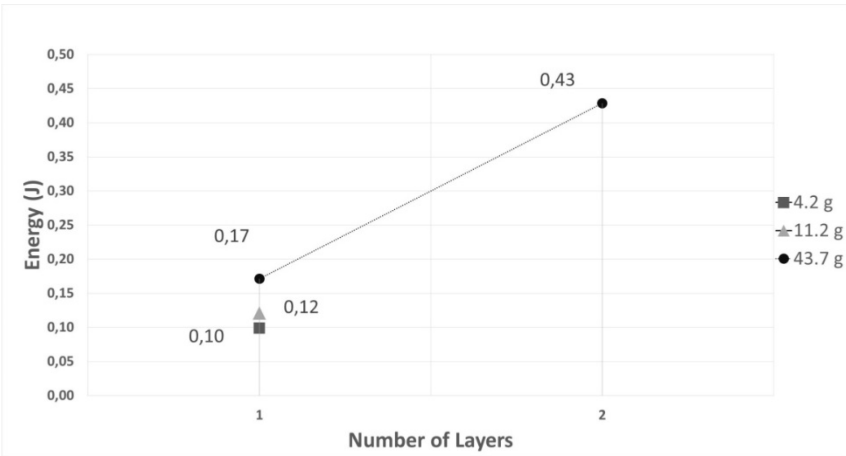

Figure 4. 20x20cm square target span – effect of target span and ball weight

Energy absorption during impact depends on the position of the contact between the sample and the projectile. Steel balls of 4.2g, 11.2g, 43.7g and 84.3g were dropped onto the paper samples. The experiments shown in Figure 3 and 4 were conducted with square frames. However, in order to clearly see the effect of impact position as a function of distance from the center position, a frame with a circular free span area was necessary. The position of impact was measured from the center of the sample in the cross manufacturing direction of the paper. Figures 5-13 shows the drop test results with 4 different balls to determine the effect of impact position on single and if applicable two and three layers.

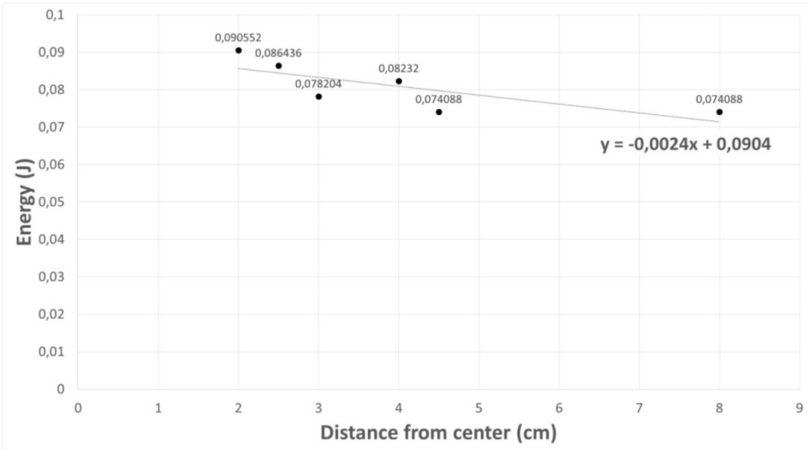

Figure 5. 20cm diameter circular target span with 4.2g ball and 1 layer paper

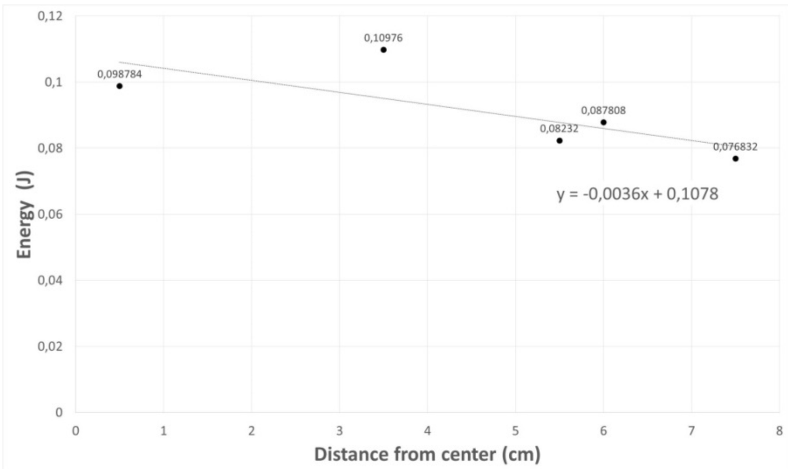

Figure 6. 20cm diameter circular target span with 11.2g ball and 1 layer paper

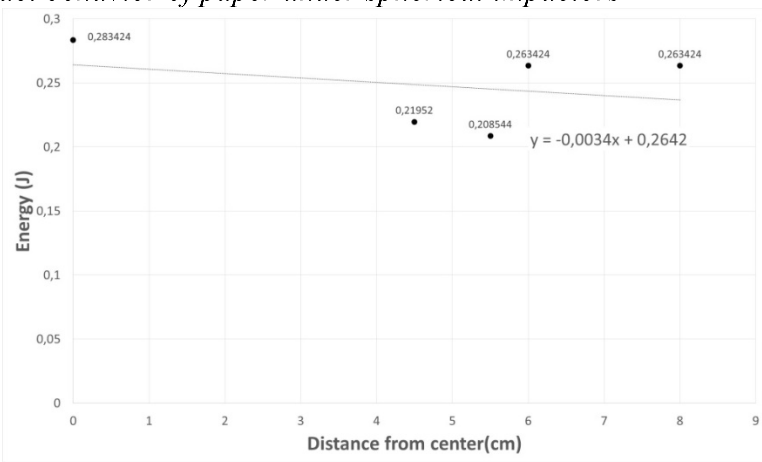

Figure 7. 20cm diameter circular target span with 11.2g ball and 2 layer paper

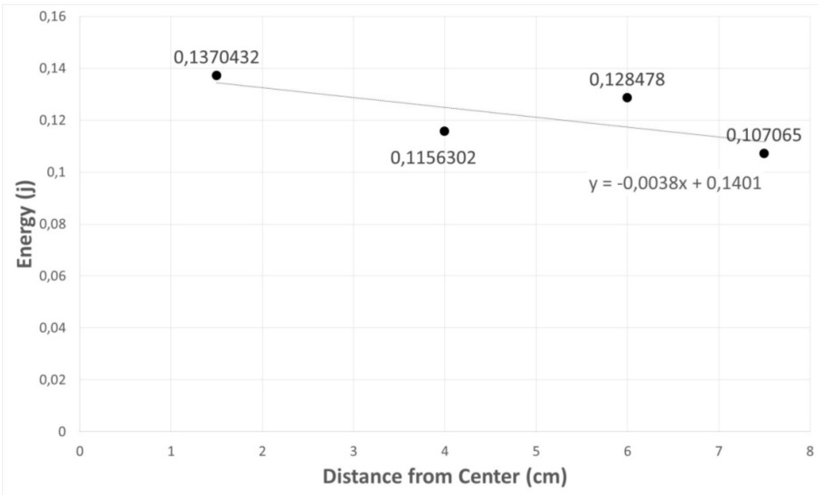

Figure 8. 20cm diameter circular target span with 43.7g ball and 1 layer paper

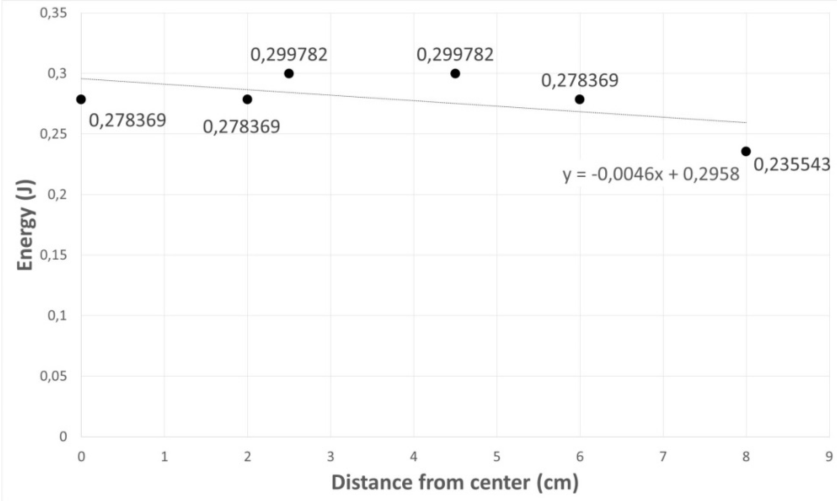

Figure 9. 20cm diameter circular target span with 43.7g ball and 2 layer paper

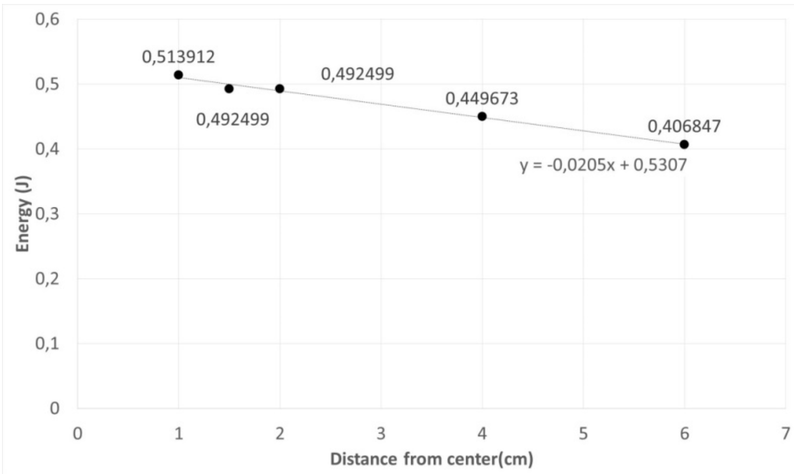

Figure 10. 20cm diameter circular target span with 43.7g ball and 3 layer paper

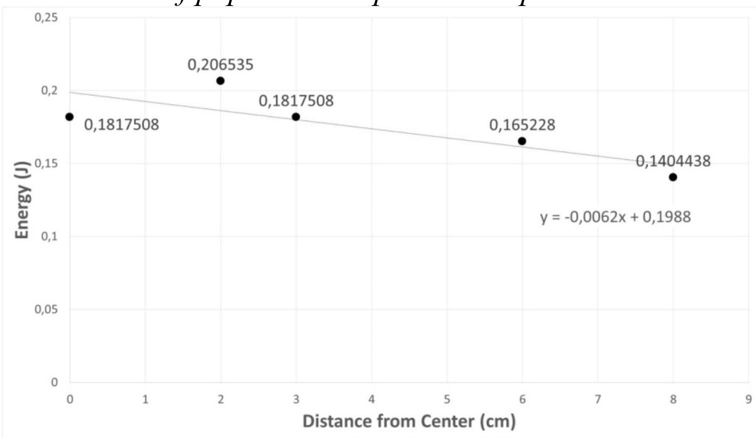

Figure 11. 20cm diameter circular target span with 84.3g ball and 1 layer paper

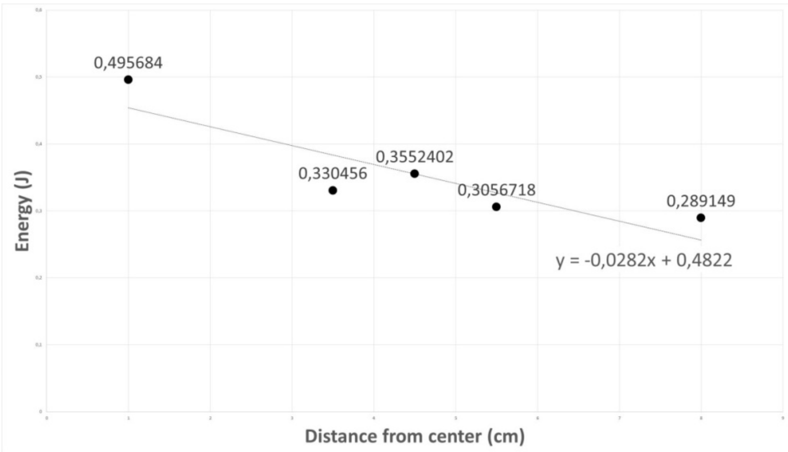

Figure 12. 20cm diameter circular target span with 84.3g ball and 2 layer paper

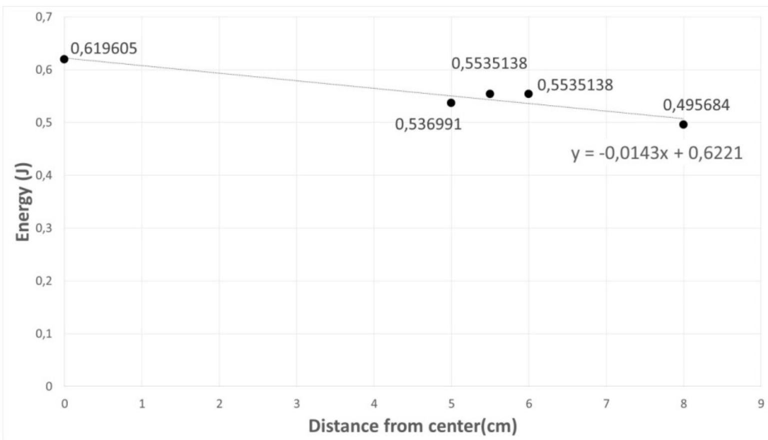

Figure 13. 20cm diameter circular target span with 84.3g ball and 3 layer paper

The drop weight tests with circular frames shows that an increased ball weight and diameter leads to an increased energy absorption by paper. The impact position significantly effects the amount of energy absorption. The maximum energy absorption occurs at the center of the frame. The energy absorption linearly decreases and reaches its minimum at the edge of the frame. This phenomenon occurs due to the spring effect at the center of the target span. If the impact position is near the edges of the frame, then the paper is stiffer and an easier penetration occurs.

3. Conclusion

The effects of target span area, number of layers, diameter and weight of the impactor and the position of penetration were experimentally analyzed on the energy absoption of commercial copy paper within this study. A larger target span leads to a higher energy absoprtion due to a higher spring effect of the paper. The energy absoption is maximum at the center of the free target area and minimum at the edges of the frame. This phenomenon is also explained with the highest spring effect at the center and the lowest spring effect of the paper at the edges. The decrease of energy absorption from the center to the edges was almost linear for the circular frame. Increased number of layers linearly increases the energy absorption. Increased ball weight equivalently means increased ball diameter. Higher ball weights and diameters led to a higher energy absorption because of the higher impact surface between the ball and the paper.

References

[1] Swinehart, D., Broek, D. (1995) Tenacity and fracture toughness of paper and board. Journal of Pulp and Paper Science, 21(11), J389-J397.

[2] Wellmar, P., Gregersen, Ø. W., Fellers, C. (2000) Predictions of Crack Growth Initiation in Paper Structures Using a J integral Criterion. Nordic Pulp and Paper Research Journal, 15(1), 4-11.

[3] Uesaka, T., Okaniwa, H., Murakami, K., Imamura, R. (1979). Tearing resistance of paper and its charactersation", Japan Tappi Journal, 33(6), 403-409.

[4] Makela, P., Fellers, Ch. (2012). An analytic procedure for determination of fracture toughness of paper materials. Nordic Pulp and Paper Research Journal, 27(2), 352-360.

[5] Wang, D. (2009). Impact behavior and energy absorption of paper honeycomb sandwich panels. International Journal of Impact Engineering, 36, 110-114.

[6] Yasui, Y. (2000). Compression breakage properties research on the honeycomb paperboard", Packaging Engineering, 27(1), 37-39.