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Tear Resistance of Laminated and Non-laminated Paperboard Types Ivory and Duplex in Packaging Materials

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Abstract.
A paperboard is a packaging material that has the disadvantage of being easily torn. One of the techniques used to overcome this is lamination. Two types of paperboard are often used as packaging materials, namely duplex and ivory. This research aimed to analyze the tear resistance comparison between duplex and ivory paperboard types. There are four types of samples in this research, namely duplex non-lamination, duplex lamination, ivory non-lamination, and ivory lamination. The variations of duplex and ivory grammation used include 350 gsm, 300 gsm, 270 gsm, 250 gsm, 230 gsm, and 210 gsm. Measurement of tear resistance refers to SNI 1974:2012 using the Elmendorf method. Each sample was measured for the CD and MD directions. The results showed that for the same grammage, the tear resistance of ivory was greater than that of duplex. The highest increase in tear resistance occurred in duplex and ivory with grammatical 210 gsm. The percentage increase in tear resistance of duplex and ivory with grams of 210 gsm, 230 gsm, 250 gsm is more than 20%, while for higher grams the percentage is less than 15%. The higher the grammage, the lower the percentage increase in tear resistance.

Keywords: paperboard, duplex, ivory, tear resistance

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1. INTRODUCTION

There are about 7 billion people on this planet, unless there are really isolated ones of modern civilization, people are constantly touched by packaging in various ways [1]. The packaging used today has undergone many developments. According to an expert from Russia, Cyrek, packaging is “a physical structure suitable for a product, designed to protect it from damage and reduction in quality, protect the product during the packaging transportation process (utility function) as well as provide information about the product and present it aesthetically (promotional function).”[2] In simple terms, the law explains that the meaning of packaging is a product that is marketed “made from any material, intended for storing, protection, transportation, delivery or presentation of products, from raw materials to processed goods" [3]. Human daily life always depends on packaging. For example, when buying food, you must use packaging to wrap it. According to Anggarwal et al [4], the design and development of the initial stages of food packaging from packaging materials is a complex technical because several packaging functions, a package must be fulfilled simultaneously. Packaging function for food packaging systems is defined as "PCCC" which stands for Protection, Containment, Communication, and Comfort. The function of packaging as protection and containment is fundamental. Additional functions such as communication and comfort are increasingly important. From environmental aspects,the function of packaging as protection and containment requires the highest attention when determining the age of the packaged product and with this possibility it will minimize wastage of food products before final consumption. Accordingly, the selection of packaging materials during the technical development of food packaging systems is not easy and requires critical examination.

In terms of packaging materials, there are many materials available today, ranging from traditional to advanced. Traditional packaging materials include plant leaves, bamboo, tree bark, woven grasses, reeds and animal organs. Some types of traditional materials are still used today, but most have been abandoned because their function is not optimal in protecting products. Modern packaging that is currently produced by the packaging industry includes plastic, paper, wood, glass, metal, bioplastic, edible film and others.[5][6][7][8] Apart from plastic, the type of packaging material that is often used in the packaging printing industry, especially food packaging, is paper. The following is paper consumption data in several countries, paper consumption per capita in the United States reaches about 324 kg, Belgium about 295 kg, Denmark about 270 kg, Canada about 250 kg, Japan is around 242 kg, and Indonesia is currently around 32.6 kg per capita. Paper demand prospects increased on paper packaging due to increase online shopping trends through e-commerce and the development of healthy lifestyle trends. According to Bank Indonesia, e-commerce transactions in 2020 increased 23.1% when compared to 2019 to Rp. 235 trillion and predicted to rise even higher in 2021 amounting to 33.2% with transaction value amounting to Rp. 337 trillion [9].

There are several types of paper that are commonly used as product packaging materials, one of which is paperboard. The main difference between paper and paperboard is the grammage, paperboard having a grammage of more than 250 gsm. Paperboard generally has many layers with more thickness than paper. Paperboard can be produced in a single Fourdrinier wire, a single cylinder former, or a series of formers of the same type or a combination thereof. 3D forming techniques can be used for advanced design of carton packaging materials to overcome the failure of the deep drawing method.[10][11][12] However, there are two types of paperboard that look familiar and are often used, namely duplex and ivory.[5] The physical appearance of duplex and ivory paper can be distinguished from their surface appearance. These two types of paperboard have two different surfaces. In duplex, one side is white and the other side is gray as seen in Figure 1(a). Meanwhile, ivory has the appearance of one side having a smooth surface and the other side not being smooth but with the same color, namely white, as seen in Figure 1(b).

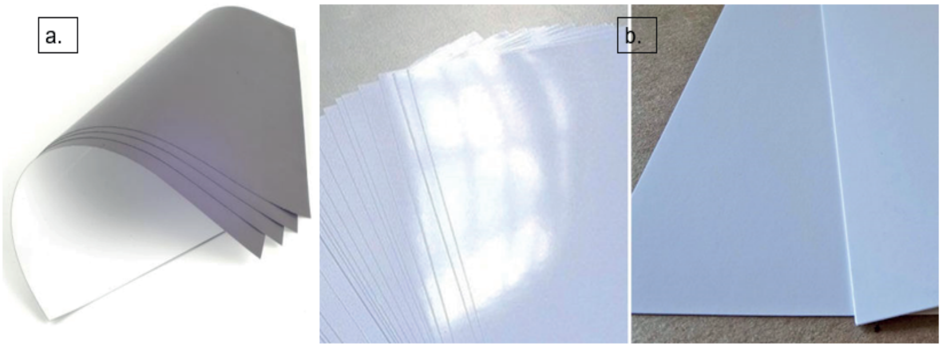


Figure 1: Physical appearance of this type of paperboard: (a) Duplex, (b)Ivory.

Duplex is made from 100% recycled paper and often contains impurities such as real paper ink, giving it a gray color. To prevent its use from surfaces that come into direct contact with food, duplex is coated. Duplex is one of the cheap papers whose appearance and strength can be improved by using whiteboard as a coating and is mainly used in tea and cereal cartons as an outer layer. Whiteboards are made using a bleaching process. Bleaching treatment is given to increase the white color and is mainly used as a coating in food cartons. Heat sealing ability can be achieved by coating with wax or laminating with a thin layer of polyethylene. The second paperboard, namely ivory, it is often referred to as foodboard. Ivory is made from 100% pure bleached pulp for food packaging, available in single layer or layered form.[11][10] Ivory on both sides is white because it comes from real pulp so there is no ink contamination. This type of paperboard is more expensive than duplex. Paperboard is generally used as primary and secondary packaging. The advantages of paperboard compared to other types of packaging include its relatively affordable price so that the selling price of the final product can be compromised, the packaging material can also be recycled so it is more environmentally friendly, it is food grade so it is relatively harmless to health, and this packaging can be used as primary, secondary or tertiary packaging.[13][14][15] Despite its many advantages, paperboard has disadvantages, namely that it cannot be used to package liquid products, it burns easily when heated, and is unable to withstand heavy and rough products because it is easily torn and hygroscopic. Paperboard material is hygroscopic, meaning it can absorb water molecules from its environment well. This hygroscopic property greatly influences changes in the physical properties of paperboard, so special treatment is needed to minimize its absorption capacity. Several special treatments can be carried out, for example water proof, grease proof, chemical proof treatment and lamination processes. Lamination is a special treatment that is often carried out to minimize the absorbency of paperboard.[13][5] Lamination is a general term for joining two or more thin layers so that it can maintain the properties of the layer, correct its deficiencies, and add desired properties to a layer [16]. The purpose of lamination on paperboard is to provide protection for the packaging so that it is more resistant to water and direct sunlight. Apart from that, lamination also functions to increase its tear resistance. This means that laminated paperboard does not tear easily when exposed to external influences such as water, oil and pressure. Tear resistance is one of the physical properties of paper that must be tested to determine its value. The tear resistance of paper can be determined by measuring its value using the Elmendorf tool.[5] No researcher has yet tested how much the tear resistance value of duplex and ivory type paperboard increases after being laminated compared to non-lamination. Pulp and paper researchers from China, Yushuang Zhaoa et al, conducted research on the effect of strengthening the carboxymethylated hemicellulose fraction on paper strength [17]. There is also research from Clelia Covino on tomato plant-based lignocellulosic fiber treated with enzymes. The resulting paperboard is characterized by its physical, mechanical and chemical properties. [18] In this year (2023), Na Li et al. have conducted research on new fabrication of hydrophobic poly(p-phenylene terephthalamide) paper with superior tear strength and high dielectric breakdown strength [19]. From several articles that the author has read, no researcher has analyzed the tear resistance of duplex and ivory either before or after lamination. Because the tear resistance of this paperboard is not yet known, it is necessary to carry out this analysis.

2. METHODOLOGY/ MATERIALS

The focus of this research is to analyze the comparison of the tear resistance values of duplex and ivory type paperboard. There are two types of treatment for these two types of paperboard, namely laminated and non-laminated paperboard. The duplex and ivory grammars used as samples are all paperboard grammars sold on the market. The grammatical variations are 350 gsm, 300 gsm, 270 gsm, 250 gsm, 230 gsm, dan 210 gsm. The lamination process is carried out in the Packaging Materials Laboratory, Tower Floor 2, Creative Media State Polytechnic. The lamination machine used is an FM 380 roll laminating machine. The thermal laminating method is used with a temperature of 100^{o}C, a glossy lamination type. Testing of tear resistance values on paperboard was carried out in the Graphic Materials Laboratory, Graphics Department, Creative Media State Polytechnic, Jakarta. The process of testing tear resistance on duplex and ivory is shown in Figure 2 below.

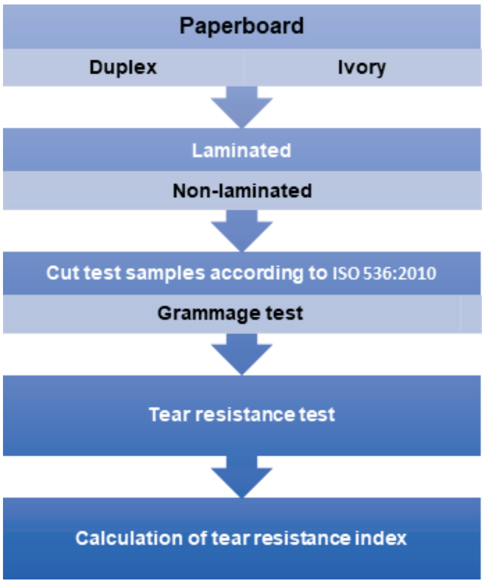


Figure 2: Research design.

The tool used to measure tear resistance is Elmendorf as can be seen in Figure 3.a. This test refers to ISO 1974:2012, namely by using a test sample measuring 7.6 cm x 6.4 cm. To test tear resistance we need to enter data on grammar of the paperboard.

Grammage data does not follow records from stores where duplex and ivory were purchased. The grammage is obtained by weighing the mass of 10 cm x 10 cm of paperboard and then calculating the grammature with the following equation:

$$Grammage\ of\ paperboard = \frac{mass\ (10cmx\ 10\ cm)\ of\ paperboard}{paperboard\ surface\ area}$$

The thickness and tear resistance values of duplex and ivory can be seen directly on the test equipment screen. However, to get the tear resistance index value, both must be calculated using the following equation:

$$Tear\ resistance\ index\ of\ paperboard = \frac{Tear\ resistance of\ paperboard}{grammage\ of\ paperboard}$$

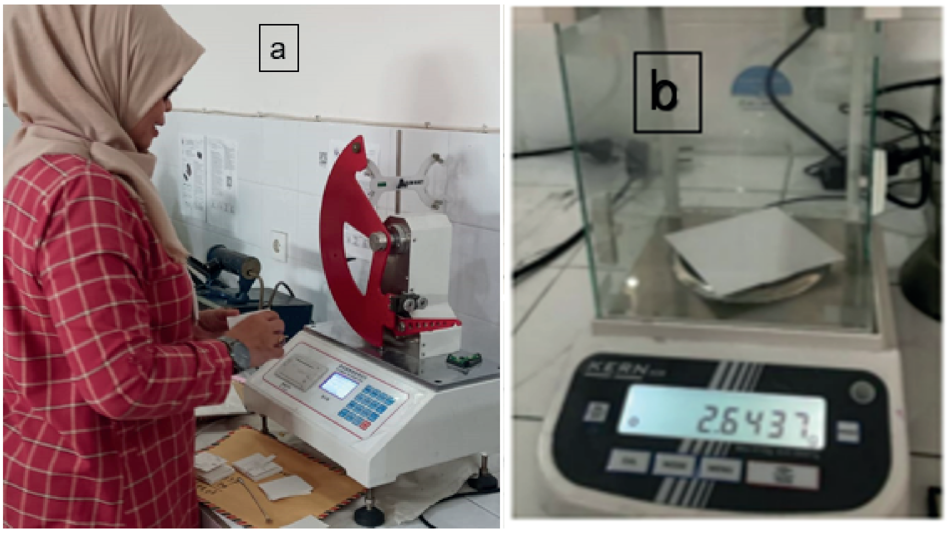


Figure 3: The tool of tear resistance test of paperboard, (a) Elmendorf tear test, (b) Analytical balance [5].

3. RESULTS AND DISCUSSIONS

In this research, the Elmendorf tool was used to determine the tear resistance of paperboard. The principle of testing paperboard tear resistance with Elmendorf is the average impact force required to tear a test object (paperboard) which is initially obtained by measuring the work done in tearing the test object at a predetermined distance. The test object used measures 7.6 cm x 6.4 cm (ISO 1974:2012). This test equipment consists of a sector-shaped pendulum equipped with a clamp. The pendulum must be parallel to the clamp in a fixed position. This position has maximum potential energy. The test object is attached to the two clamps, then an initial tear is made between the two clamps. This initial tear is 1 cm as shown in Figure 4. The pendulum is freed to rotate so that the clamp on the pendulum moves to tear the test object. Tear resistance can be read directly on the Elmendorf device monitor screen. The scale displayed on the monitor screen shows the force in units of newtons or percent of the potential energy of the pendulum used so that the tear resistance can be calculated. Tear resistance is the force required to initiate or continue tearing of paperboard under certain conditions, or the average impact force required to tear a test sample that has been given an initial tear. This force is equal to the work done to tear the test object divided by twice the length of the tear. Tear energy is the work done to tear the test sample.

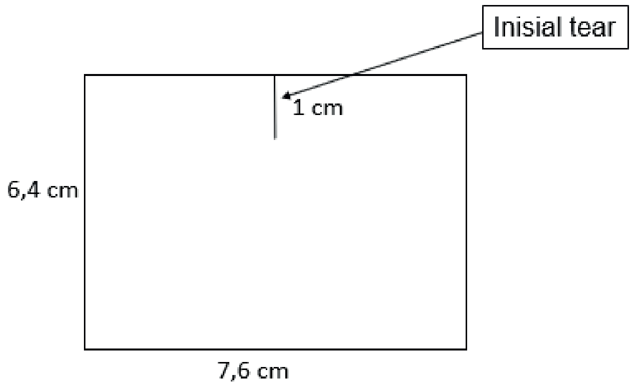


Figure 4: The size of the paperboard used as a test object (a) Test sample with fiber cross direction (CD), (b) Test sample with fiber cross direction (MD).

There are two types of paperboard used in this research, namely duplex and ivory. In previous research, the author had conducted research on the tear resistance of 310 gsm and 260 gsm ivory laminated with matte and glossy finishes.[5] Because in previous research, the grammatical variations used did not represent all types of paperboard on packaging, this research was carried out using duplex and ivory paperboard with grammatical dimensions of 350 gsm, 300 gsm, 270 gsm, 250 gsm, 230 gsm, and 210 gsm. Duplex and ivory are the two types of paperboard that are most often used as packaging materials in the Indonesian packaging industry. There is no official data about this yet, but from several industrial internship experiences of Packaging Engineering students, Polimedia, it was found that both are always used. Based on SNI for paper, there are several characteristics of paper that determine its suitability for use as packaging material. One of them is its tear resistance. Studies on the tear strength of paperboard generally consist of examining the factors that influence the tear strength of paperboard. Among these factors, fiber type, paperboard grammar, and paperboard thickness.[5] In this test, no variations in lamination were carried out because the tear resistance of paperboard is not influenced by the type of lamination (doff and glossy). The following is the grammage of duplex and ivory which have been measured using a analytical balance (Table 1). These grammage values will later be input into the Elmendorf device to determine the tear resistance of duplex and ivory (Table 2).

The grammage laminated paperboard is higher than non-laminated paperboard. This is due to the additional material in the form of plastic covering the paperboard. The plastic used to laminate the test samples has a thickness of 15 μm with a glossy type. Both duplex and ivory use the same type of plastic. The grammage used when testing tear resistance is the value obtained from the test results, not the grammage value

Table 1: Data on grammage test results of duplex and ivory.

Grammage based on shop records (gsm)	Grammage based on test results (gsm)			
	Duplex		Ivory	
	Non-laminated	laminated	Non-laminated	laminated
210	202	220	205	223
230	235	244	233	247
250	251	259	249	257
270	269	281	265	279
300	303	320	300	322
350	348	361	346	359

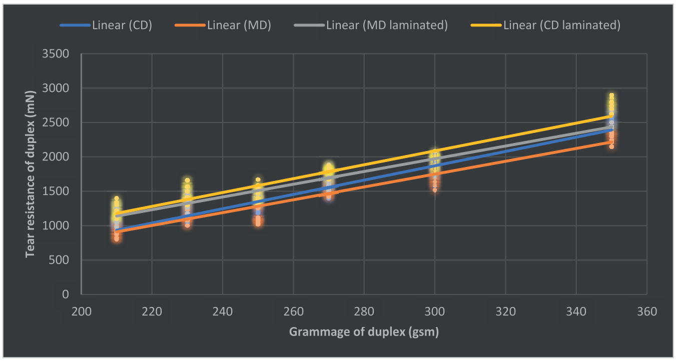
from shop records. There is a slight difference in the grammatical values of the two but they are still within the range. At the same grammage, the tear resistance values of non-laminated or laminated ivory are higher than duplex in both CD and MD directions. This is because the fibers in duplex are shorter than ivory fibers. Duplex is 100% made from recycled materials.[11] Meanwhile, ivory comes from real pulp.[12]

Table 2: Data on Paperboard Tear Resistance Test Results.

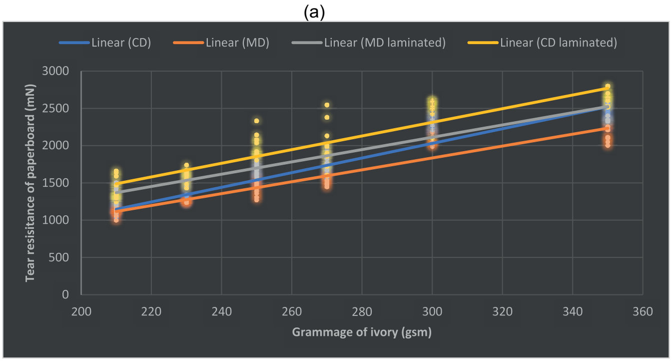
Grammage (gsm)	Tear resistance (mN)							
	Duplex				Ivory			
	CD	CD laminated	MD	MD laminated	CD	CD laminated	MD	MD laminated
210	1004 ±56	1214 ±91	923 ±88	1152 ±115	1144 ±49	1434 ±134	1102 ±51	1337 ±93
230	1190 ±96	1485 ±109	1159 ±100	1399 ±121	1284 ±40	1591 ±88	1251 ±13	1521 ±65
250	1234 ±101	1470 ±66	1178 ±134	1437 ±107	1572 ±87	1994 ±136	1422 ±95	1707 ±88
270	1572 ±86	1798 ±57	1524 ±67	1675 ±110	1624 ±54	1947 ±155	1540 ±58	1814 ±98
300	1766 ±95	1948 ±86	1684 ±90	1937 ±93	2283 ±98	2506 ±137	2057 ±68	2310 ±74
350	2544 ±96	2768 ±80	2285 ±70	2509 ±89	2408 ±113	2655 ±84	2124 ±90	2420 ±93

In duplex testing, the tear resistance test results were obtained as in Figure 5. There are 4 types of test samples, namely duplex non-lamination in the direction of the CD fiber, duplex lamination in the direction of the CD fiber, duplex non-lamination in the direction of the MD fiber, and duplex lamination in the direction of the MD fiber.

In the graph (Figure 5. a), it can be seen that duplex lamination in the direction of the CD fiber has higher tear resistance than the other 3 types of samples, including duplex lamination in the direction of the MD fiber. MD of paperboard is the direction of the paperboard fibers that is parallel to the direction of the paperboard travel path along the paper machine, while CD is the direction that is perpendicular to MD. Paperboard properties such as tensile, folding, and pressure(compression) are very significant in both directions. This is often related to the direction of the grain, but more important is the fact that MD paper experiences higher drying than CD. If fiber alignment is the main reason for the differences in strength properties, then it will be clear that there is a large difference in the amount of tear strength of MD and CD. The nature of tear strength depends entirely on the properties of the fiber itself such as the length and width of the fiber and the strength of the fiber.[20][21]



(a)



(b)

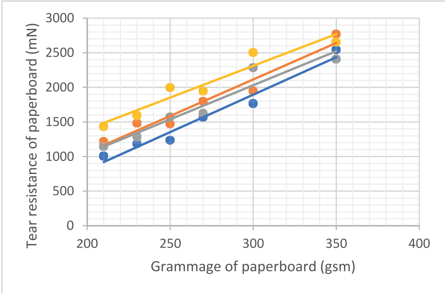
Figure 5: Graph of the relationship between grammage and tear resistance of (a) duplex paperboard and (b) ivory paperboard.

The lamination process also greatly influences the tear resistance of paperboard. The percentage increase in tear resistance resulting from lamination is above 20% for duplex grammages 210 gsm, 230 gsm and 250 gsm. For higher grammage, a decrease in percentage is obtained. In duplex 270 gsm, 300 gsm, 350 gsm, the percentage increase in tear resistance resulting from lamination is below 15%. Detailed data on the percentage increase in tear resistance can be seen in Table 3. The same thing happens with ivory as with duplex, at low grammage, the percentage increase in tear resistance of the laminate results reaches more than 20%. For high ivory grams, the percentage increase in tear resistance does not reach 20%. This is in line with previous research results that the tear resistance value of matte and glossy ivory laminates increased by 16% - 20%.[5][22][23] This means that paperboard laminated with plastic is more difficult to tear than paperboard that is not laminated.

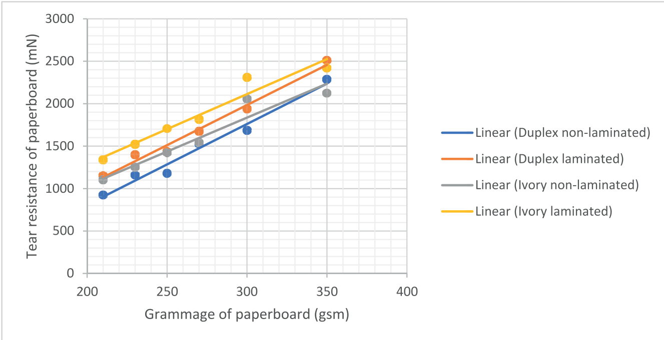
Table 3: Data on the percentage increase in tear resistance resulting from lamination.

Grammage (gsm)	Percentage increase in tear resistance of duplex			
	Duplex		Ivory	
	CD laminated	MD laminated	CD laminated	MD laminated
210	21%	25%	25%	21%
230	25%	21%	24%	22%
250	20%	22%	27%	20%
270	14%	10%	19%	18%
300	10%	14%	10%	12%
350	9%	9%	8%	10%

Figure 6 shows a graph of the relationship between grammage and tear resistance of non-laminated paperboard (duplex and ivory) in the (a) CD fiber direction and (b) MD fiber direction. From the graph, it can be seen that the tear resistance of non-MD laminated paperboard is the lowest. This is in accordance with the theory that the tear resistance of paper in the CD fiber direction has a higher value than in the MD fiber direction. The tear resistance value for ivory 350 gsm is higher than ivory 300 gsm, 270 gsm, 250 gsm, 230 gsm, dan 210 gsm. This shows that the grammage affects the tear resistance value, where the greater the grammage value, the higher the tear resistance of the paper.[23][21] These results are in accordance with the theory that there are several factors that influence the tear resistance of unlaminated paperboard, including fiber size, fiber direction, number of bonds between fibers, grammage, water content, humidity, and adhesive on the paper.[24] Tear resistance of paper that has a long fiber size is higher than paper with a short fiber size[21]. The CD direction requires a greater force compared to MD (to make the paper tear) .The bonds between fibers only increase tear resistance to a certain level.[25]



(a)



(b)

Figure 6: Graph of the relationship between grammage and tear resistance of non-laminated paperboard (duplex and ivory) in the (a) CD fiber direction and (b) MD fiber direction.

4. CONCLUSION AND RECOMMENDATION

The percentage increase in tear resistance of duplex and ivory with grams of 210 gsm, 230 gsm, 250 gsm is more than 20%, while for higher grams the percentage is less than 15%. The higher the grammage, the lower the percentage increase in tear resistance. Ivory paperboard has higher tear resistance than duplex. To be able to determine the effect of the thickness of the type of laminated plastic, it is necessary to test tear resistance by varying the thickness of the laminated plastic.

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