COMPARATIVE TESTING OF THE CARRYING CAPACITY OF PAPER SHOPPING BAGS

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Abstract:
Environmental awareness and sustainability are playing an increasingly important role in everyday life. With increasingly stringent regulations and social expectations, the importance of recyclable and biodegradable materials is growing. Paper bags are important for their packaging function and are also symbols of sustainable shopping habits. The popularity of paper bags has grown rapidly in recent years. The use of paper bags contributes to the creation of an environmentally conscious image. At the same time, there are a number of questions regarding the practical usability of paper bags, such as their durability, water resistance, and contribution to sustainability goals. During our everyday shopping, we often encounter paper bags of varying quality and reliability. Therefore, we examined how well these bags meet different consumer needs and conditions of use. We explored how willing where costumer to pay extra for sustainability. The aim of our research was, on the one hand, to review the historical, environmental, and sustainability aspects of paper bags. We analyzed the experiences and habits of paper bag users through a questionnaire survey. In addition, we conducted various physical and mechanical tests focusing on the load capacity, moisture resistance, and durability of paper bags. The aim of the research is to provide a comprehensive overview of how paper bags meet sustainability and practical expectations.

Keywords: *paper bag, shopping bag, paper-based packaging, paper bag capacity, carrying capacity, environmentally conscious shopping, sustainable packaging*

1. INTRODUCTION

During our everyday shopping, we often encounter paper bags, the quality and reliability of which vary greatly. This was partly what motivated us to examine how well these bags meet different consumer needs and conditions of use. We analyzed how willing useres are to pay extra for sustainability and how these expectations are reflected in the range of products available on the market. Following a historical overview of paper bags, we analyzed their environmental and sustainability aspects. By evaluating the results of various physical and mechanical tests, we demonstrated the practical applicability of paper-based packaging materials.

2. PAPER BAGS AS TRANSPORTATION MEDIA

2.1 Historical overview

The development of paper bags began during the Industrial Revolution. The first major breakthrough came in 1852 with Francis Wolle's patented paper bag making machine, which made production faster and more efficient, paving the way for the spread of paper bags in the United States and Europe. [1] In 1871, Margaret E. Knight invented and patented the first machine for manufacturing flat-bottomed bags, which made paper bags more stable and easier to handle. This made it possible to transport heavier items safely. Walter Deubener added handles to paper bags. By the 1910s, shoppers could use these to conveniently carry their purchases *(Figure 1).* This type became known as "Deubener's Shopping Bag" and quickly spread to department stores. [2]

Figure 1: Charles Stilwell's patent for the SOS paper bag [2]

From the mid-20th century onwards, paper bags were pushed into the background by the emergence of lighter and cheaper plastic bags. Recently, however, environmental concerns and the demand for sustainability have brought paper bags back into the spotlight. Modern paper bags are made from sustainable raw materials, such as paper certified by the Forest Stewardship Council (FSC) or the Programme for the Endorsement of Forest Certification (PEFC). The popularity of paper bags in grocery stores is growing steadily as shoppers increasingly prefer environmentally friendly packaging solutions over plastic bags. In addition to being practical, paper bags also emphasize sustainability. Paper bags can also play a prominent role as a popular marketing tool. The Big Brown Bag *(Figure 2)* is an excellent example of how a simple paper bag can become a well-known trademark.

Figure 2: Macy's iconic "Big Brown Bag" [2]

It has become a symbol of the Macy's chain of stores and represents sustainability, elegance, and practicality all at once. The popularity of paper bags in recent years is due not only to their environmentally friendly properties, but also to increasingly stringent regulations.

2.2 Raw materials and manufacturing process of paper bags

The kraft paper, is made from long-fiber cellulose fibers. This structure ensures the paper's high tensile strength and flexibility. Sulfate paper is naturally brown in color but is also available in a bleached version. It is popular for advertising and premium bags. It is also outstanding in terms of sustainability, as it often comes from FSC or PEFC certified forests, which ensure that the raw material comes from a sustainable source. Recycled paper has weaker mechanical properties than kraft paper, making it ideal for packaging lighter products such as gifts and smaller items. The production of recycled paper requires fewer natural resources, thus reducing the ecological footprint. Coated papers can be used for a variety of purposes. Waterproof coatings prevent moisture from seeping through, making them ideal for packaging baked goods and other products exposed to moisture. Grease-resistant coatings prevent oily or greasy foods from damaging the paper, so they are often used in fast food or bakery packaging. Compostable coatings are made from natural, plant-based materials that ensure the bags biodegrade while providing an environmentally friendly alternative. [3] The production of paper bags is a complex, mechanized process that can be divided into several stages:

- preparation of raw materials,
- printing,
- shaping and gluing,
- forming handles,
- quality control and packaging.

3. QUESTIONNAIRE SURVEY

We conducted a non-representative questionnaire survey (199 respondents) to identify the habits and problems associated with the use of paper bags. We compared the responses with the measurement data of the paper bags tested. 78.4% of the respondents were middle-aged women (between 35 and 50 years old). Based on the answers to the question "How often do you reuse paper bags?", 40.6% of respondents reuse paper bags frequently. Only 8.6% of respondents said they never reuse them. The answers to the question "How suitable do you think paper bags are for everyday use?" show that the majority of respondents, 54.3%, consider paper bags less suitable for everyday use. 29.9% of respondents consider them suitable for everyday use, while 12.7% consider them completely unsuitable. Interestingly, only 6 people, or 3.1% of respondents, consider paper bags to be very suitable for everyday use. The data also highlighted the limitations and reservations associated with the everyday use of paper bags. Responses to the question "What problems have you encountered when using paper bags?" included the following: paper bags weaken more easily when exposed to moisture and are not durable enough for everyday use *(Figure 3).* In other words, the physical weaknesses and limitations of paper bags are the main problem. The majority of respondents, 54.3%, therefore consider paper bags to be less suitable for everyday use.

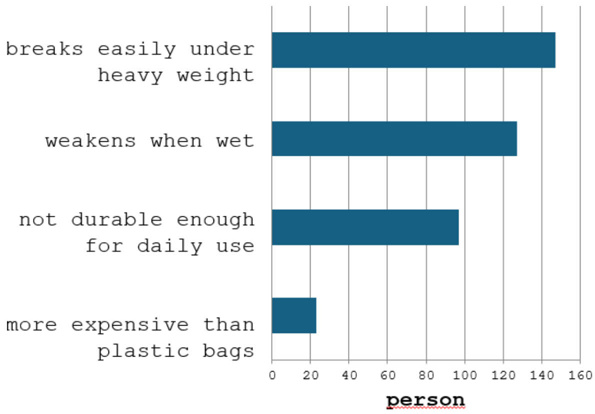

Figure 3: The most common problems associated with the use of paper bags

4. PAPER BAGS AND THEIR PHYSICAL TESTING

For the test, we selected six paper bags of different sizes and load capacities, representing a wide range of products available on the market *(Table 1).* We determined the performance of the bags as their load capacity, moisture resistance, and mechanical stability. This was done in order to confirm or refute user concerns with the measurement results.

Table 1: Parameters of the paper bags tested

sample	designation	size* [cm]	max.load capacity [kg]
1	Tesco brown ribbon-handled shopping bag	32 x 16 x 43	8
2	Traditional brown twisted-handle paper bag	32 x 12 x 41	3-4
3	Ribbon-handled brown shopping bag	32 x 17 x 46	12
4	Rossmann ribbon-handled white shopping bag	32 x 14 x 45	8
5	White twisted-handle paper bag	32 x 12 x 41	3-4
6	White ribbon-handled paper bag	28 x 14 x 35	5

*(width x depth x height)

4.1 Determining the volume of paper bags using filler material

The volume of paper bags was determined in accordance with the provisions of standard MSZ EN 13590:2003, which provides precise guidelines for measuring the volume of packaging units. The bulk density of the plastic granules used to determine the volume of the paper bags was also calculated according to the above standard. [4] During the test, the volume of 5 samples from each of the 6 types of bags described above was measured *(Figure 4), (Table 2).*

Figure 4: Volume measurement of sample 3

Table 2: Parameters of the paper bags tested

sample	calculated volume [l]
1	27.62
2	15.74
3	24.61
4	20.16
5	15.74
6	13.72

The volume of the bag was calculated using formula (1)

$$\mathbf{V} = \frac{m}{\rho} \tag{1}$$

where:
ρ: the bulk density of the granules (kg/m^3),
m: the mass of the granules (kg),
V: the volume of the cylinder (1 liter = 0.001 m^3).

The volume measurement tests provided a comprehensive overview of the capacity and functionality of different paper bags. The results showed that the volume of the bags can vary significantly, which can serve different purposes. The bags with the largest volume (samples 1 and 3) are suitable for transporting larger and heavier items, which can be advantageous when transporting food or clothing products, for example. These bags allow for multifunctional use due to their high load capacity and large storage capacity. The smaller bags (samples 5 and 6) are ideal for smaller products such as medicines, cosmetics, or small gifts due to their smaller size.

4.2 Maximum load capacity test

The purpose of the maximum load capacity test is to determine whether the paper bags comply with the maximum load capacity specified by the manufacturer. The test was performed in accordance with standard MSZ EN 13590:2003. The bags, filled with plastic granules to their maximum load capacity, were placed on a lifting machine, suspended by both handles. The lifting machine raised the bag to its highest position and then began the repetitive lifting and lowering movement specified in the standard (10-10 up and down movements). We observed when the bag began to tear or deform. A maximum crack length of 30 mm was allowed during the movement. If the crack exceeded 30 mm or the handle broke, the bag was classified as defective. The results obtained in kilograms were compared with the maximum load capacity specified by the manufacturer. The bags showed no significant cracks or damage to the handles during the tests, so all samples met the carrying capacity requirements. The tests confirmed that the paper bags can be used safely within the values specified by the manufacturers and meet customer requirements.

4.3 Overload testing

The purpose of the overload test was to assess how paper bags react when the maximum load specified by the manufacturer is exceeded. This test is important because users often overload bags, which can affect their lifespan and reliability.

The bags were first tested with a load 25% greater than the maximum load capacity specified by the manufacturer, and then with a 50% overload. We examined the structural stability of the bags, looking for signs of tearing or deformation. Based on the test results, we can conclude that all bags successfully withstood the 25% and 50% overload exceeding the manufacturer's specifications. This shows that the structural stability of the bags is adequate for extreme loads that may occur during everyday use. The tests were performed under dry conditions. The behavior of paper bags may differ in wet environments.

4.4 Moisture effect and load capacity test

The way paper bags react in a wet environment, especially when their maximum load capacity is exceeded, simulates real-life situations where bags often come into contact with moisture. We sprayed of 12 ml and 24 ml of water onto the inner surface, side walls, and bottom of the bags. After 2 minutes, when the water had been absorbed and the strength of the paper material had adapted to the effects of moisture, we tested the bags' maximum load capacity with a 25% overload. The bags were subjected to repeated lifting and lowering movements every 30 seconds for 10 minutes. During this time, we documented changes in the strength of the material and signs of structural weakening or tearing *(Table 2)*.

Table 2: Parameters of the paper bags tested

sample	12 ml water spray tear time [min]	24 ml water spray tear time [min]	note
1	540	192	the bottom part tore
2	no tear	no tear	the bag remained intact
3	no tear	no tear	the bag remained intact
4	no tear	162	the bottom part tore
5	138	-	the bottom part tore
6	102	-	the bottom part tore

During the tests, we found that the performance of paper bags varies significantly under the combined effects of moisture and load. The 12 ml water spray caused varying degrees of structural weakening and tearing in samples 1, 4, 5, and 6, while samples 2 and 3 were more resistant. Under the effect of 24 ml of water spray, the tear time decreased further, especially for samples 1 and 4, whose lower parts tore after an average of 3.2 and 2.7 minutes, respectively. Samples 5 and 6 did not survive the entire test time even with 12 ml of water spray, breaking after an average of 2.3 and 1.7 minutes, respectively *(Figure 5)*.

Figure 5: Visual inspection after moisture effect and load capacity testing

4.5 Cobb$_{120}$ test (water absorption capacity)

Moisture significantly affected the stability of the bags, typically at the bottom. Paper bags are often exposed to wet environments, and it is necessary to understand how they behave in such situations. We used the Cobb$_{120}$ test to examine the water absorption capacity of paper bags. We focused primarily on the surface water absorption capacity of the paper used as the raw material for the paper bags. The test was performed in accordance with the ISO 535:2023 standard, which specifies the water absorption capacity of paper and cardboard. Lower Cobb values generally indicate better water resistance, while higher values indicate greater water absorption and poorer moisture tolerance. We observed different results for each sample, reflecting the relationship between water absorption and material weakening. The numerical data and textual evaluation of the observations of the test are presented in *Table 3.*

Table 3: Evaluation of the Cobb test

Sample	Coob value [g/m²]	Observation
1	33.77	The bottom tore, but not at the folds; the material weakened on its own
2	34.19	Remained stable, but the gluing weakened due to moisture
3	32.98	The most stable sample; no material weakening or tearing occurred
4	33.70	Both the bottom and the folds tore; both the material and the folds weakened
5	31.28	The bottom and shoots tore quickly
6	24.73	The bottom and shoots tore quickly

Low Cobb value and water resistance – Sample 6 showed the lowest Cobb value (24.73 g/m²), indicating good water resistance. However, this sample was not durable during testing, as structural weakening led to rapid tearing. This suggests that a low Cobb value does not necessarily guarantee bag stability if the material strength is poor. Medium Cobb value and stability – despite its medium Cobb value (32.98 g/m²), sample 3 was the most stable, with no tearing or material weakening. This suggests that, in addition to water absorption, the structural design and material quality of the bag are also key factors. Higher Cobb value and adhesive weakening – despite the high Cobb value (34.19 g/m²) of sample 2, it did not tear, but the adhesives weakened under the influence of moisture. This suggests that appropriate structural elements can improve the durability of the bag, even if the material has a high water absorption capacity. High Cobb value and rapid weakening – the higher Cobb values of samples 1, 4, and 5 (31.28–33.77 g/m²) led to weakening of the lower parts and folds. When exposed to moisture, these bags tore quickly, especially at the folds. A low Cobb value does not guarantee durability, as mechanical strength is also key. Medium Cobb values (32–34 g/m²) generally offer a good balance between water resistance and stability, while high Cobb values can result in poorer moisture tolerance, especially due to structural weakening of the folds and bottom sections. To improve the performance of paper bags, it is recommended to reinforce these critical areas and use more water-resistant materials and adhesives. [5]

4.6 Square meter mass testing and evaluation

Determining square meter mass is essential for evaluating the quality of paper bag material, as the density and thickness of paper directly affect its mechanical properties, such as load-bearing capacity and water resistance. We used the ISO 536:2020 standard, which specifies the procedures for measuring square meter weight. [6]

Square meter weight can be determined using the following formula:

$$\mathbf{V} = \frac{\boldsymbol{m}}{\boldsymbol{\rho}} \qquad (2)$$

where: ρ is the mass per square meter (g/m²),
m is the mass of the test piece (g),
A is the area of the test piece (m²).

Determining the square meter weight of the raw material of the paper bags tested revealed the extent to which the density and thickness of the material affect the durability, water resistance, and load capacity of the paper bags *(Table 4).*

Table 4. Evaluation of square meter weight test

sample	square meter weight [g/m²]	observation
1	85.33	The bottom tore, but not at the folds; the material weakened on its own
2	108.33	It remained stable, but the bonds
3	123.33	The most stable sample, with no material weakening or tearing were weakened
4	105.33	Both the bottom and the folds tore, with both the material and the folds weakening
5	107.33	The bottom and folds tore quickly
6	102.33	The bottom and folds tore quickly

Low basis weight and poor mechanical stability – the low basis weight of sample 1 (85.33 g/m²) resulted in poor mechanical stability. During testing, the material weakened independently and the bottom tore, while the folds remained intact. This suggests that the low basis weight is less suitable for long-term load-bearing capacity, especially when exposed to moisture.
Medium basis weight and balanced performance – Sample 2 (108.33 g/m²) and Sample 4 (105.33 g/m²) had medium basis weight, which showed more stable performance. Sample 2 remained stable, but the adhesives weakened, while Sample 4 both broke and the material and the folds broke. This means that although medium basis weight generally shows better performance, the weaker adhesive and fold sensitivity degrades the overall durability.
High basis weight and excellent stability – Sample 3 (123.3g/m²) had the full basis weight and showed excellent performance in the tests. Neither appeared discontinuous, suggesting that stability for mechanical water resistance cannot be achieved with the higher basis weight.
Average weight and poor performance in wet conditions – despite their average weight per square meter, sample 5 (107.33 g/m²) and sample 6 (102.33 g/m²) showed poor performance in wet conditions. In both samples, the bottom and folds quickly tore, indicating that the composition of the material and the quality of the adhesives greatly affect the stability. This suggests that weight per square meter alone is not enough to ensure the durability of the bag.
Based on the tests, the cracking always occurred at the bottoms and along the folds, where the effects of moisture and load were concentrated, with only the 105–120 g/m² range proving to be the most balanced in terms of Cobb tests and mechanical stability. It is recommended to improve the performance of paper bags by reinforcing the bottoms and folds, and by using more water-resistant adhesives, materials and water-repellent coatings.

5. CONCLUSION

The aim of the research was to investigate the durability, water resistance and practical applicability of paper bags, with particular attention to sustainability aspects. The results of the physical and mechanical tests show that the load capacity of the paper bags generally meets expectations, and in some cases even proved to be stable under overload. Even at 25% and 50% increased loads, they showed significant pressure, which demonstrates the reliability of the paper bags in everyday use. However, the performance of the bags is significantly reduced, especially with poorer material quality or weaker adhesive patterns. This suggests that although the paper bags perform well in dry conditions, their resistance to moisture is limited, which may be a problem in certain application areas. The results of the Cobb test showed that bags with low water absorption are not always more durable if the bag is prone to rapid tearing due to structural weakness of the material. In contrast, samples with medium Cobb values generally showed better stability, indicating that not only water resistance, but also material strength and structural design are key factors in the design of paper bags. These factors open up further development opportunities for manufacturers, especially in the areas of moisture resistance and structural stability. The results of the research can contribute to a broader understanding of the applicability of paper bags.

6. REFERENCES

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