FACTORS DETERMINING THE QUALITY OF PRODUCTS MADE FROM RECYCLED PAPER

Associate Prof. PhD Temenuga Stoykova
Assist. Prof. Velichka Marinova

Introduction

Paper and its derivative products play an important part in almost every aspect of human life. It is used as a printing and writing material, for storage and dissemination of information, but it can be further used as a wrapping paper, packaging material and for design purposes. Indeed, paper has an unlimited potential, particularly fiber paper materials which find valuable application in the cellulose and paper industry. According to the preliminary statistics of the Confederation of European Paper Industry (CEPI), world production of paper and cardboard in 2013 increased by 1%, with only a slight increase of 0.2% in 2012. The total paper production of member states of the confederation amounted to 91 million tons in 2013, with paper and cardboard packaging having the largest share (45.9%), whereas usage of recycled paper has risen by 0.5%. The role of paper as a raw material for the paper industry seems to be steadily on the rise. Recycled fibers from waste paper (WP) constitute about 50% of the fiber raw materials used in the production of paper and paperboard. In Bulgaria only, the production of paper and cardboard for 2012 amounted to 218 000 tons, while collected waste paper for the same year amounted to 181 645 tons. As compared to other European countries, Bulgaria is reported to have a high level of waste paper usage – 70% for 2012, in contrast to paper collection and recycling where the country is lagging behind. Over the period 2005 – 2012, collection of paper accounted for 35-46%, while recycling of paper ranges somewhere between 30-57%.

An ever growing demand for paper and paper-based products combined with a shortage of wood fiber resources, determines the need for an alternative supply of fiber raw materials. Among other alternatives, recycling seems to be a feasible solution.

in providing an adequate substitute for the primary wood fibers. In the modern cellulose and paper industry, secondary fibers derived from waste paper exhibit a number of advantages\(^6\) as compared to the fresh fiber materials, such as low cost and energy requirements and contained negative impact upon the environment. This in turn explains their high degree of consumption and competitiveness with an increased emphasis on the quality of products made from secondary fiber raw materials and the need to improve said quality.

The purpose of the present study is to identify the main factors and their effect upon the quality of products made from recycled paper materials.

Quality of products made from recycled paper materials

The quality of manufactured products is an extremely important factor which impacts the business operations. Advances in the technical and technological level and quality of products is a necessary condition so that the company can meet its business objectives, become competitive and yield higher profitability\(^7\). The quality of goods is a combination of their intrinsic properties and characteristics, underlying their suitability to meet existing or anticipated needs in accordance with their intended use, under certain conditions of use or exploitation\(^8\). It is built alongside the product and is subjected to the influence of various factors.

Factors influencing quality are those impacts, conditions and circumstances seen in their totality and interrelatedness, which can induce a change in products composition, structure and characteristics. Owing to the impact of said factors and depending on the specifics of consumption, different consumer profiles can be outlined.

Paper recycling involves processing of paper and paperboard, aiming to recover its original properties and/or production of new paper-based products. Paper reveals a wide range of consumer properties which account for its quality even though these can be subject to certain reversible and irreversible changes during the recycling process. In the authors’ opinion, the main factors determining the quality of products made from recycled paper are as follows:

- **Grading of fiber raw material:** identification and classification; characteristics and composition of recycled paper;
- **Technological processes involved in paper processing:** standards on quality of fiber pulp made from recovered paper and type of end product; recycling technology; the processing cycle and its impact upon the quality of the final product, etc.;
- **Use of additives/additional substances:** composition, type and role played in improving the quality indices.

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Factors influencing the quality of products made from recycled paper

1. Fiber raw materials and their impact

Paper recycling usually involves sorting out recovered paper by grade or type in accordance with the European list of standard grades of waste paper and cardboard, recovered paper and board\(^9\). During secondary processing, waste/recovered paper is separated into different groups and grades which are subject to specific recycling processes.

For the purposes of recycling, an overall classification of recovered paper is deemed necessary, i.e. to classify and determine its composition in order to improve its recyclable content and obtain a quality paper product. Classification is done following EU standard adopted by the European Paper Industry, which is also applied in our country (BSS EN 643:2003), aiming to systematize the great variety of waste/recovered paper types and outline categories further classified into groups of recyclable waste materials.

We hereby assume that adequate and quality sorting of paper stock and its proper identification and characterization would largely help researchers in their study of recyclable paper materials towards a higher quality end product, and save them a lot of energy and chemicals for production\(^10\).

Degrading the quality of waste materials comes as a result of their multiple treatment and the increased content of contaminants in the secondary fiber. These contaminants contain various fibrous or non-fibrous components which have been introduced as inclusions in the paper composition during the process of fiber paper production\(^11,12\).

Certainly, the characteristics and content of the secondary fiber pulp tend to influence the quality indices of the recycled product. Fibers contained in the waste paper (WP) manifest qualities different from those of the virgin fiber as they have undergone a mechanical and chemical treatment and ageing. In the opinion of some researchers\(^13\) these changes arise from the lowered values of the tear resistance indices, double bending, etc., due to the decreased bonding strength between the fibers of paper made of 100%, secondary material as compared to paper made from primary/virgin fibers under otherwise equal conditions. In contrast, the indices for tear resistance, opacity and absorbency are several times higher.

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Moral and other authors argue that in order to maintain the quality of the end product it is necessary to elucidate on the relationship between fiber pulp and paper which implies characterization of fiber morphology, and pulp content. The above authors affirm that fiber length affects considerably the paper strength. On the other hand, the width of the fibers and the thickness of their walls can affect their flexibility and tendency to shrink (thickening) during the manufacturing process which in turn affects the final paper product and its properties. Fibers with thin walls shrink easily, and if used for making coated paper they tend to bond readily in the structure of the paper sheet making it denser, stronger and more uniform/smooth. Some authors have proved that the anatomy and composition of fibers can be used as additional factors in assessing paper suitability for packing materials. According to Rozalinov study and analysis of the properties of output materials and their influence on the quality factors of produced packing material is crucial to the design, construction and choice of material from which paper packaging is made.

With the growing use of secondary fibers, it becomes even more important to study their effect on the properties of the resulting product. Decrease in the strength properties of the secondary product can be attributed to a change in the physical or chemical state on the fiber surface, which reduces the formation of hydrogen bonds. Other authors also report that recycled fibers can be more solid with reduced tendency to swell in water and are more likely to retain their shape. During examination of 11 types of fiber materials in Canada, Howard found that the recycling process and its impact is largely dependent upon the type of fiber material.

The low quality of waste paper is due to its large content of unusable materials such as non-paper ingredients and unwanted paper and board. Iosip, A. et al. have examined their influence on the recycled pulp made from different grades of waste paper, collected by the households. It was found that even a small quantity (3 – 5 %) of the brown packing paper and corrugated board can have a strong effect on the optical properties of de-inking paper, reducing its brightness (whiteness) and increasing the number and size of spots from brown fiber scales during a deinking operation (or paper


laundering) of waste/recovered paper from 1.11 group (newspapers: magazines 50:50\%). With packing paper classified as group 1.04 (recovered corrugated board: other types of packing paper and board 70:30\%), the higher content of writing and printing paper accounts for the so-called ash content and reduced mechanical strength of the recycled pulp.

The fiber paper content is an indicator of any paper type. To determine said content, one must identify the fiber components in the paper and paperboard, taking into consideration the origin of fibers. Research conducted by Radu and other authors found that by applying a qualitative and quantitative microscopic analysis it is possible to define the size of anatomical (or constituent) elements in a mass ratio and in this way prevent counterfeiting of products made from paper.

In view of the above analysis we can conclude that proper identification and characterization of recycling paper on the basis of its anatomy, morphology and composition will facilitate effective quality control of the secondary fiber pulp. Among basic properties which can be influenced are strength and density of the paper sheet. Furthermore, study of anatomical content could help prevent counterfeiting of paper products and enhance product design from recycled materials. The purer the raw material, the higher the quality of resultant products. The fibrous raw material has a strong influence upon the optical and mechanical consumer properties of manufactured paper and paperboard.

2. The Impact of Technological Processes

Characteristics of the fibrous raw material namely, its composition, morphology, performance and intended use determine the specific processing technology and the processes involved in it.

_Paper recycling_\(^{22}\) is a specific flow process in paper mills which involves treatment of recovered paper and recycling it into new paper and board or other paper-based products. The quality of newly produced paper products is greatly influenced by their _cycle of recycling_.

There is a limit to the number of times a piece of paper, a corrugated box or other paper materials can be recycled, but in practice, each time paper is reprocessed, the fibers become shorter which affects the overall performance characteristics of materials input into production. As a consequence, the quality of final products is also affected and virtually, after each processing cycle, waste materials tend to decline in strength\(^{23}\). According to some authors\(^{24}\), the recycled fiber is useless after being recycled.

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3 or 4 times since the quality of the fiber pulp severely deteriorates – practically speaking, the number of cycles to which a fiber from the reprocessed paper can be subjected is under 2. Venditti found that during a 5 cycle process of recycling in laboratory conditions, the mechanical properties of the cellulose fibrous pulp generally decrease, with about 8% after 0 – 1 cycle, and 10% after 1 – 5 cycles of treatment and more. In their study Puziryov and Kovaleva indicate that after the 5th recycling, the tear resistance index is most affected due to shortening of the average fiber length. In her work Stoychev points out that the strength of recycled paper tends to go down by 20% with each successive cycle of processing together with paper hardness. According to Kovaleva, the flow sheet for treatment of waste pulp can be provisionally separated into three types: flow sheet for production of different grades of packing paper and board products; flow sheet for production of sanitary and household paper and production of paperboard and print and writing paper. Venditti treats newspaper production as a separate type.

Puziryov also argues that the technology of waste paper recycling is more complicated than treatment of the primary or virgin pulp as it contains a number of contaminants and other unwanted ingredients such as additives, fillers, coatings, etc. This suggests that the stage of preparation of the fibrous material for the recycling process should be very well planned. In this regard, some authors make it clear in their studies that the basic requirements when designing the technological process are as follows: removal of the maximum possible amount of foreign inclusions at the very start of the technological process: defibration (breaking the paper down into tiny strands of cellulose), rough sorting and cleaning; reducing the number of technological operations for the purpose of using a more effective equipment.

Depending on the type of recycled fiber products, the recycling process passes through different stages: defibration, grinding, refining, cleaning, screening, de-inking, dispersion, bleaching, pressing, drying, rolling, treatment of waste water and waste from production, etc.

Nazhad concludes that the impact of recycling upon fiber properties depends on defibration and the history of paper making. According to him, one of the negative impacts of recycling is impairment of the paper-forming/mechanical properties of paper.

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Articles

and paperboard. The authors who have been involved in the study of the processes of paper recycling claim that major changes in the fibers have been observed during grinding and drying operations.

Following the effect of mechanical grinding, Lumiainen\textsuperscript{34} examines and identifies specific changes occurring in the cellulose fiber materials such as increase in the tensile strength and hardness of materials, better tear resistance and bursting strength. Depending on the materials’ origin, the tear strength of coniferous fibers initially improves to subsequently deteriorate while deciduous fibers at first exhibit a considerable tear strength which later declines due to prolonged grinding. The author also reports a change in other indices such as lower air permeability, volume, opacity, dispersion of light and slightly decreased whiteness.

Some researchers\textsuperscript{35} have arrived at the conclusion that pulp drying is responsible for the decline in paper strength. The hardening of the surface limits the binding of fibers, while internal curing reduces their agreement. Both effects may limit the compaction of the paper sheet and reduce its strength. Strength of recycled fibers recovered from corrugated board is influenced by the process of grinding, pressing, drying and other physical operations which affect and modify the porous structure of the cell walls of the fibers\textsuperscript{36}.

The effect of recycling upon the properties of paper products varies in terms of the type and intended use of fibrous materials. Serious changes in the properties of fibers can be observed after their grinding and drying. If carefully prepared and conducted, the process of grinding will have a positive effect and increase the tensile strength, tear resistance and breaking strength of said materials. Also, proper monitoring of the process can reduce the negative impact upon performance characteristics such as air permeability, hygroscopic quality and whiteness. On the other hand, proper optimization of the pressing and drying processes can enhance material structure and limit the negative influence on the properties of final products, including paper strength and hardening of the paper surface.

The recycling process has a strong effect on paper tensile strength and the resulting paper products. On the basis of the above literary review we can conclude that regeneration of fibers is good until the third cycle.

3. Effect of chemical substances put in use

Many researchers have come to the conclusion that multiple treatment of secondary fiber pulp can affect negatively the paper forming properties and quality of paper, which is then subjected to various stages of refining. Particles from printing ink and


stickies (sticky materials like glue and adhesives) in the pulp can impair the quality of finished products and reduce the efficiency of the paper machine and because of that additional chemical bonding substances (CBS)\textsuperscript{37} need to be introduced. These substances have natural or synthetic origins which are meant to improve paper quality and facilitate the process of paper making. Various chemical bonding substances (CBS) find application in improving the properties of newly formed paper. Their use in the paper recycling process is mainly to increase the paper strength and enhance the process of de-inking.

It has been found that the addition of an amine functional polyvinyl alcohol at the wet end of the production of recycled paper products leads to the desired improvement of their strength under wet or dry conditions\textsuperscript{38}. Zhang M. et al.\textsuperscript{39} managed to increase the strength of recycled unbleached kraft pulp by adding a few water soluble substances or a number of additives, whereas other researchers\textsuperscript{40} claim that pre-treatment using different chemical substances is able to compensate for the loss of strength. It is well-known that addition of low doses of poly-electrolytes containing amine functional groups to recycled kraft liner show a favourable effect on the tensile strength\textsuperscript{41}. Chemical treatment through de-inking of mixed office waste paper results in better tensile strength and resistance using 10\% succinic acid, 5\% sodium dihydrogen phosphate\textsuperscript{42}. Adding cationic starch will significantly enhance the strength of sheet material from recovered corrugated cardboard and neutral sulphate polycellulose pulp\textsuperscript{43}. A team of researchers\textsuperscript{44} found that the type of surfactants and cellulose enzymes used in the process can affect the whiteness, the index of contamination and de-inking. Oxidative enzymes\textsuperscript{45}

can be used to enhance the quality of recycled fibers in terms of their strength and optical properties. These are seen as the eco-friendly alternative to the standard process of chemical de-inking of recycled paper as through their use demand for chemicals is lowered, production costs are reduced and negative impact on the environment is contained, while similar optical properties as with conventional deinking process are maintained. Lee C., at al. argue that proper regulation of enzyme hydrolysis is crucial for improving the quality of recycled paper. According to other authors, use of enzymes improves the quality of fibers and helps restore the lost strength in the recycling process. Bajpai et al. state that enzymes have the potential to resolve fiber recycling problems, such as de-inking, presence of sticky substances, the dehydrating quality of recycled fiber, defibration, etc. Literature review made by Puneet et al., summarizes the role of enzymes in enhancing optical properties of de-inked fiber materials.

Type and content of chemical bonding substances (CBS) is governed by the state and quality of raw material fed in production – its category, composition and degree of recycling. Use of small quantities of CBS seems to be one of the main factors influencing the quality of new paper products. Said substances improve process running and help change raw materials properties in the manufacturing of products with specific function and design. Various chemical substances also have a positive influence upon the optical and strength properties of fiber materials and their quality characteristics.

**Conclusion**

Optimization of the activities involved in the collection and sorting of waste paper, which aim to ensure the highest quality of secondary fiber pulp and overcome the deficiencies of the technological process of recycling, upgrade of technologies and use of CBS are among the key factors which help obtain final products with desired properties.

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Factors which influence the quality of products made from recycled paper have been identified according to the type of fiber material, technological process and CBS put in use. The latter’s impact upon the properties of recycled material and quality of paper-based products has also been summarized. It was established that these impacts are interrelated and dependent upon the specifics of the paper recycling processes represented as waste paper – chemically bonded substances (CBS) – technological treatment – quality of the finished product. The purer the recycled paper, the more efficient its processing will be and the less the amount of additional substances to be used in the process. Changes in fiber strength are observed during the processes of mechanical grinding and drying, whereas the optical and strength properties of fiber material are enhanced by inclusion of small quantities of CBS. Interplay of the above-mentioned factors contribute to the formation of a set of consumer properties of the final products.

FACTORS DETERMINING THE QUALITY OF PRODUCTS MADE FROM RECYCLED PAPER MATERIALS

Assist. Prof. Velichka Marinova
Assoc. Prof. Dr Temenuga Stoykova

Abstract

The quality of products from recycled paper materials is determined by factors, which upon their interaction contribute to the formation of a complex of consumer properties of the end-products. The underlying factors are in a state of interconnectedness and interdependence formed by the peculiarities of the processes of recycling paper. The relation can be presented as follows: waste paper – supplementary chemical substances – technological processing – quality of the end-product. The degree of purity of paper, its composition and rate of recycling, the technological stages of milling and drying as well as the adding of small amounts of HBs contribute in the highest degree to improving the strength and optical properties of the products from recycled paper materials.

The objective of the present article is to identify the main factors and the effect they have on the quality of products from recycled paper materials.

Keywords: quality, recycling, factors.