IQ-SPECTROSCOPIC ANALYSIS OF THE INTERACTION OF VARIOUS FIBERS IN THE EXPERIMENTAL PAPER COMPOSITION

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Abstract. *This article presents the results of an IR spectroscopic analysis of experimental packaging paper samples produced from textile fabric waste and two types of adhesive materials. The study examines the spectral characteristics and interactions of different fibers within the paper composition.*

Today, the demand for paper products is steadily increasing. According to statistical data, around 410 million tons of paper and cardboard are produced worldwide each year, and this figure is expected to reach 450 million tons by 2027.

In our Republic, the demand for paper and cardboard products amounts to 350 thousand tons. The sharp growth in the demand for packaging materials has led to an increased need for packaging paper.

At the same time, environmental protection and the efficient use of non-renewable resources have become some of the most pressing global issues. In particular, the excessive use of polyethylene products and the accumulation of non-biodegradable waste pose a serious threat to the ecological balance. Therefore, it is essential to develop effective technologies for utilizing biodegradable and eco-friendly materials, including non-wood local raw materials in the production of paper products. Such an approach not only contributes to resource conservation, but also supports environmental protection through waste recycling.

The main goal of this study is to develop packaging paper intended for the printing industry by recycling certain types of polluting industrial waste, particularly textile industry waste, and to prepare recommendations and proposals for the effective organization of practical activities in this field.

For the production of packaging paper, three types of waste from modern textile fabrics — selected to meet current consumer demands — were chosen as samples. As adhesive materials, two types of binders were used: hydroxypropyl methylcellulose and modified cationic starch.

To carry out this experiment, sample papers were produced and their quality was evaluated in accordance with an approved technological regulation at the testing center of the “Global Komsco Daewoo” joint venture.

Paper samples containing textile waste were prepared in different ratios using two types of adhesives (see Table 1).

Table 1.

Composition of Experimental Paper Samples

Indicators	**Paper composition by fiber type, %**					
Basis weight, g/m² (ISO 536–1995)	90			120		
Adhesive material	**Hydroxypropyl methylcellulose**			**Hydroxypropyl methylcellulose**		
Variants	№1	№2	№3	№4	№5	№6
Cotton cellulose, %	100	50	-	100	50	-
Textile waste, %	-	50	100	-	50	100

This table shows the fiber composition and adhesive types used in the six variants of experimental paper samples, differing in fiber ratios and adhesive materials.

In regulating the technological parameters of paper production, the properties and structure of the fibers introduced into the pulp composition play a crucial role in optimizing the paper's characteristics**.** These factors significantly affect the bonding strength between cellulose and fibers, determining the inter-fiber bonding forces within the paper sheet formed from refined cellulose fibers.

During the experiment, to study the interaction between textile fabric waste fibers and cellulose**,** IR spectroscopic analysis was performed on the obtained paper samples (Figure 1). The IR spectroscopic study was conducted using equipment manufactured by Perkin Elmer (USA)**.**

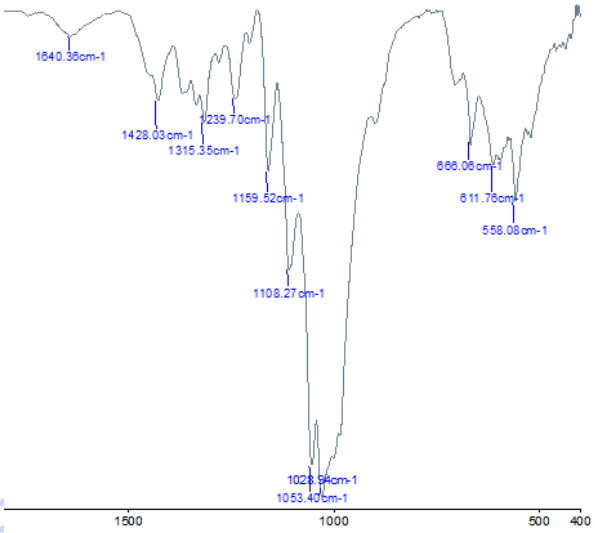


Fig. 1. IR spectroscopic analysis of experimental packaging paper sample No.1

The absorption band observed at 1640.36 cm^{-1} corresponds to the deformation vibrations of C=O or O–H bonds, which are associated with bound water molecules or secondary alcohol groups present in the HPMC structure. The signals detected at 1428 cm^{-1} and 1315 cm^{-1} indicate the δ-deformation vibrations of CH_2 and CH_3 groups, characteristic of the polymeric structure of HPMC. The peaks at 1239 cm^{-1} and 1159 cm^{-1} correspond to the stretching vibrations of C–O–C ether bonds, confirming the presence of glycosidic linkages within the HPMC structure.

The signals observed in the regions of 1108 cm^{-1}, 1053 cm^{-1}, and 1028 cm^{-1} correspond to the stretching and deformation vibrations of C–OH and C–C bonds. In particular, the broad absorption band within the 1028–1053 cm^{-1} range is characteristic of polysaccharides (PS).

In conclusion, the IR spectrum of experimental packaging paper sample No.1 clearly shows the presence of functional groups such as O–H, CH_2, CH_3, C–O–C, and C–OH, which are characteristic of both PS and HPMC. This indicates that the components in the paper composition have formed a physical mixture. Since the paper surface was not printed, no functional groups related to pigments or ink components were detected.

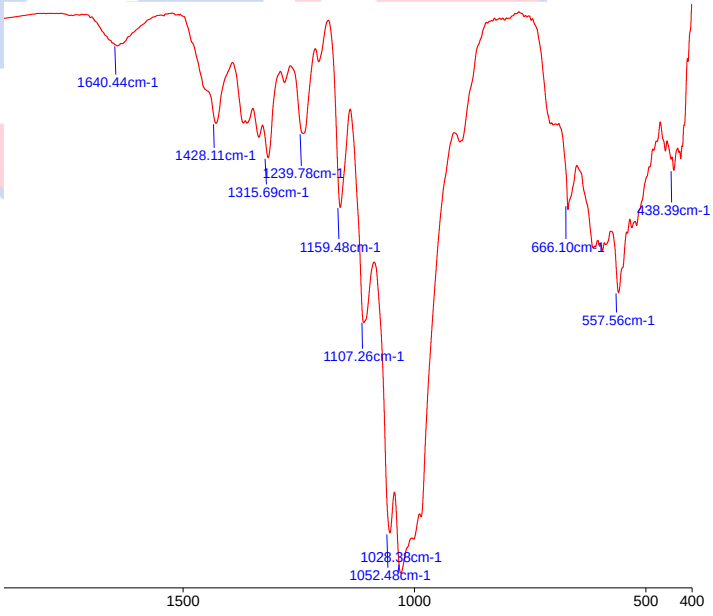


Fig. 2. IR spectroscopic analysis of experimental packaging paper sample No.2

This IR spectrum analysis was conducted for an unprinted experimental paper sample prepared on the basis of 50% polysaccharide (PS), 50% textile waste (TW), and HPMC**.**

The absorption band at 1640 cm^{-1} corresponds to the O–H deformation vibration associated with bound water or the deformation vibration of the carbonyl (C=O) group**.** This band may be attributed to moisture content or the hydrophilic nature of HPMC. The signals at 1428 cm^{-1} and 1315 cm^{-1} represent the δ-deformation vibrations of CH_2 and CH_3 groups**,** which are related to alkyl groups present in both

TW and HPMC. The 1239 cm^{-1} peak corresponds to the stretching vibration of the C–O–C ether bond, a typical region characteristic of HPMC.

The absorption bands at 1159 cm^{-1} and 1107 cm^{-1} correspond to the stretching vibrations of C–C or C–OH groups, which are characteristic signals of PS (polysaccharides) and TW (textile waste). The peaks at 1052 cm^{-1} and 1028 cm^{-1} are attributed to the stretching and deformation vibrations of C–O and C–OH groups, belonging to cellulosic substances.

In conclusion, the IR spectrum of this sample confirms the presence of functional groups characteristic of PS, TW, and HPMC, such as O–H, CH_2, CH_3, C–O–C, and C–OH. Since the sample contains no printing components, no pigment-related peaks are observed, indicating the purity of the sample and the distinct representation of its structural components.

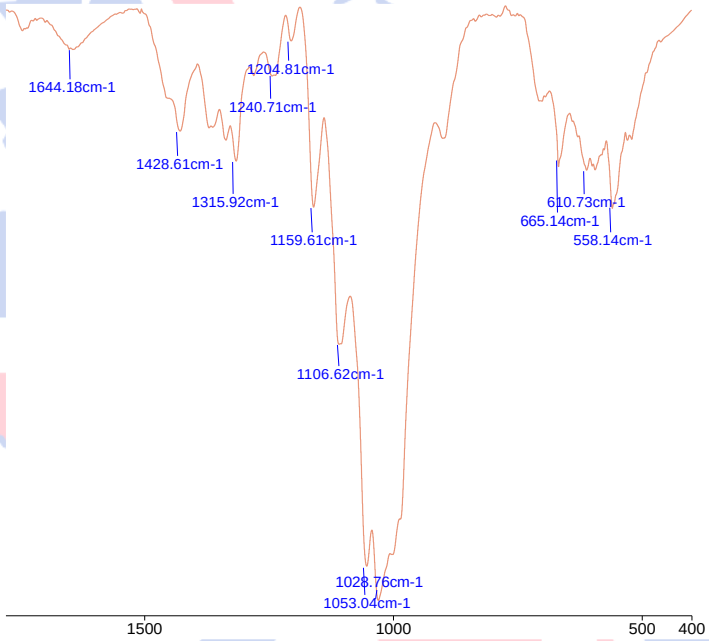


Fig. 3. IR spectroscopic analysis of experimental packaging paper sample No.4

In the IR spectroscopic analysis, the absorption band at 1644 cm^{-1} corresponds to the O–H deformation or the stretching vibration of the carbonyl (C=O) group, which may be associated with water molecules or alcohol groups present in the modified cationic starch (MCS). The bands at 1428 cm^{-1} and 1315 cm^{-1} represent the deformation (δ) vibrations of CH_2 and CH_3 groups, indicating the participation of alkyl groups in both paper cellulose (PC) and MCS.

The peaks at 1240 cm^{-1} and 1204 cm^{-1} correspond to the stretching vibrations of C–O–C ether bonds, which are characteristic of the polymeric structure of MCS. The absorption bands observed at 1159 cm^{-1} and 1106 cm^{-1} correspond to the stretching vibrations of C–OH or C–C bonds, present in both PC and MCS. Finally, the peaks at 1053 cm^{-1} and 1028 cm^{-1} are attributed to the stretching and deformation vibrations of C–OH groups.

This is very characteristic of cellulose-based structures. In conclusion, the IR spectrum of experimental packaging paper No. 4 clearly shows the functional groups (OH, CH_2, CH_3, C–O–C, C–OH) typical of PC and MCC components. Due to the absence of pigment components, no dye-specific vibrations were detected, which indicates compositional purity.

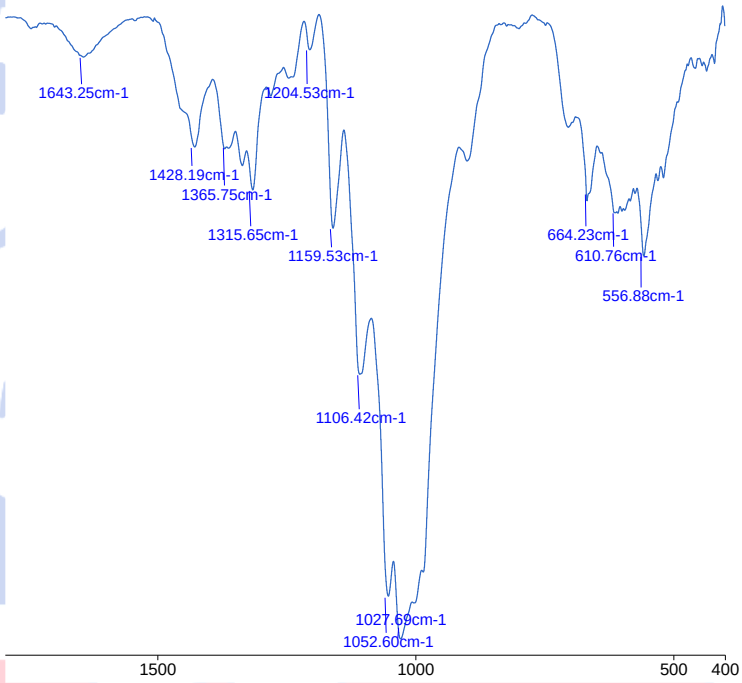


Fig. 4. IR spectroscopic analysis of experimental packaging paper No.5

In the IR spectroscopic analysis, the band at 1643 cm^{-1} may correspond to OH deformation vibrations or indicate the presence of C=O groups from water-soluble substances. The bands at 1428 cm^{-1}, 1365 cm^{-1}, and 1315 cm^{-1} are attributed to CH_2 deformation vibrations, as well as twisting of C–H and C–C bonds in MCC and TC components. The peaks at 1204 cm^{-1} and 1159 cm^{-1} correspond to stretching vibrations of C–O–C or C–O–H groups, commonly observed in polymer structures, particularly in MCC and TC. The band at 1106 cm^{-1} is associated with hydroxyl group deformation or C–O bond stretching vibrations. The peaks at 1052 cm^{-1} and 1027 cm^{-1} correspond to stretching or deformation vibrations of C–C and C–O bonds.

These peaks are very common in cellulose and its derivatives. In conclusion, since there are no pigment-related aromatic groups in this spectrum, the vibrations in the low-frequency region (700–500 cm^{-1}) are specific only to the main paper components, particularly characteristic of cellulose and MCC substances. The absence of aromatic C–H vibrations typical of pigments in unprinted paper has been confirmed.

Based on the research results, it can be concluded that during the papermaking process, TMCh fibers were found to form secondary bonds. The formation of these

bonds, resulting from fiber fibrillation, was observed to contribute significantly to positive outcomes. Moreover, when TMCh and adhesive materials were added to the paper pulp along with PS, the presence of functional groups (OH, CH_2, CH_3, C–O–C, C–OH) was identified.

In paper samples consisting of 100% PS, stretching and deformation vibrations corresponding to OH, CH, and C–O groups were also detected. The inclusion of TMCh in the paper composition led to the formation of new intermolecular bonds, corresponding to the deformation vibrations of hydroxyl groups, which produced positive effects. These bonds suggest the possibility of additional hydrogen bond formation when GPMC and MCC interact with cellulose through hemicellulose and hydroxyl groups.

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