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COST AND QUALITY FOCUSED SUITABLE BOX DETERMINATION WITH DESIGN OF EXPERIMENT: A CASE OF A GLASSWARE COMPANY

ABSTRACT

There is an increasing competition between companies for their survival in today’s business environment. Not only time but also cost parameters affect the company’s sustainability performance. Logistics as one of the core operations of companies has a large share on expenses. Transport, warehousing, administration, packaging, and other indirect costs constitute the main cost values of logistics. Especially product damages caused by incorrect packing and transportation leads to extra expenditures to the companies and damages their reputation due to the customer dissatisfaction. In order to avoid such situations, proper level of packaging for protection, transportation conditions, features of the product like fragility, compactness, must be selected and matched correctly. On the other hand, some external factors such as temperature and humidity, which affect the quality of cardboard, also need to be considered in the production phase. In this study, a Design of Experiment methodology is performed to determine the suitable conditions for increasing the strength of the corrugated cardboard box that is used by a Glassware Company operating in Turkey. 3^k full factorial design approach is implemented for the analysis and box compression test is used for measurement. The discussed factors and the interactions of the factors were evaluated with the help of Minitab software.

Keywords: Design of Experiment, DOE, 3^k Full Factorial Design, Packing, Logistics, Cost

1. INTRODUCTION

In today’s business world, there is an increasing competition between companies and operational performance management is crucial to sustain a competitive advantage and to survive. The key performance criteria such as cost, quality, time, punctuality, sustainability etc. need to be managed attentively for companies’ continuity and consistency. Cost minimization without sacrificing the desired quality became one of major concern with heightened competition. The production costs are divided into two main classes as variable and fixed costs. These costs are generally composed of materials and raw materials, labour, facility, non-recurring and purchased cost [1]. The share of these costs within the total cost varies from sector to sector. The average logistics costs in the retail sector are higher than for manufacturing companies [2]. In addition to this, according

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to various empirical surveys, the average logistics costs of an industrial enterprise account for 10-25% of total costs and logistics costs share of company turnover in developed economies tends to be at least 10 percent [3 and 4].

Logistics cost types are separated according to the functional structure at the value creation phase and appear within the value creation process. Since a wide variety of logistic cost components are defined in the literature, logistics costs are handled in different categories. Weber (1995) analyzed logistics costs under three categories, which are performance costs, operating level-based standby costs and non-operating level-based standby costs, instead of fixed and variable costs approach. Horváth and Mayer (1989) proposed a very similar categorization to Weber (1995), which include performance-related material costs, personnel costs and fixed-term costs of use for technical assets and service agreements [3]. Zeng an Rossetti [5] classified the logistics costs into six categories: transportation, inventory holding, administration, customs charges, risk and damage, and handling and packaging. According to Weiyi and Luming [6], logistics costs are divided into two main groups as explicit and invisible logistics costs. The sub classifications of this main cost group are shown in Figure 1. Havenga [7] examined logistics costs under four categories, namely transport, storage and port handling costs, management and administration costs and inventory carrying costs. For the other issues related to categorization of logistics costs, interested readers can glance at Silva, et al., [8] and Siepermann [3].

Damage cost, in other words loss cost, is described in literature as “the value of unit that will be lost, damaged or delayed” [5] and can be caused by incorrect packing and transportation. Damage cost leads to extra expenditures to the companies and damages their reputation due to the customer dissatisfaction. In order to avoid such situations, packaging and transportation conditions must be selected and matched correctly. On the other hand, some external factors such as temperature, humidity, which affect the quality of package, also need to be considered. In this study, a Design of Experiment (DOE) methodology is performed to determine the suitable conditions for increasing the strength of the corrugated cardboard box that is used by a Glassware Company operating in Turkey. 3^k full factorial design approach is implemented for the analysis and box compression test is used for measurement. The discussed factors and the interactions of the factors were evaluated with the help of the Minitab software.

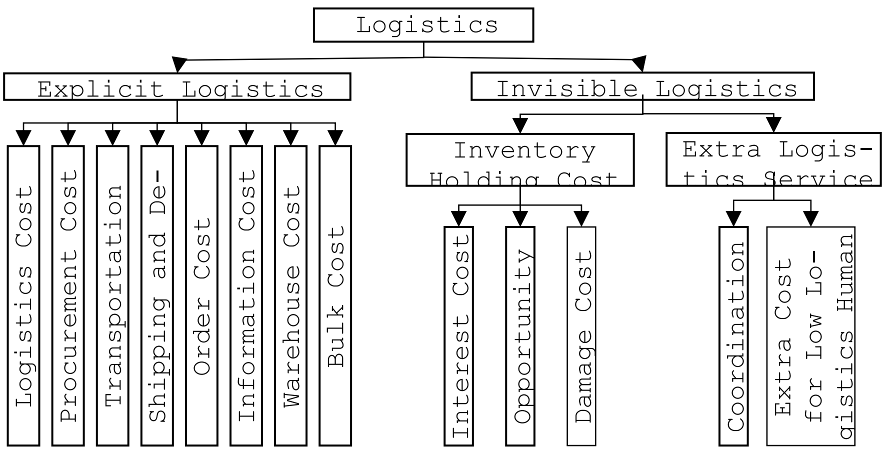

Figure 1. Logistics Cost Components [6]

The outline of the study is as follow. In section 2, literature review for design of experiment in supply chain management and logistics sectors is given. Section 3 presents the methodology and the details of the handled problem are also explained in here. The computational results are shown in section 4. Section 5 concludes the study.

2. RESEARCH SIGNIFICANCE

Design of Experiment (DOE) methods has been applied in various sciences in literature since its agricultural origin. Churchill [9} used DOE in genetic science and studied two-color spotted cDNA microarrays with a design of experiment to provide the convenient statistical analysis on the resulting data. Turley and Milliman, [10] presented a summary of the 60 published empirical studies, which were used different design of experiment technique to analyze the customer buying behavior variability in different atmospheric situations. This study is an example of DOE application in social sciences. Wahdame, et al., [11] applied DOE in chemistry science where fuel cell consumption efficiency was investigated with various operating parameters. Many more examples are available from the literature. When the studies related to the DOE in supply chain (SC) management and logistics sectors are examined, the following papers are encountered. Shang, et al., [12] researched for identifying optimum operating conditions of a supply chain with a hybrid approach that incorporates simulation, Taguchi method and response surface methodology.

Biehl, et al., [13] conducted a case study using full factorial experimental design method to analyze the performance of a reverse logistics supply chain model of a carpet manufacturing industry in the US. They used the number of collection centers, the standard deviation of the collection rate, a change in the collection rate over time, the core’s recyclability, and the control system type as factors. Average new carpet inventory level, percentage of months with backlogs, average production cushion and average post-consumer recycled content were responses. Manzini et al. [14] studied on designing a forward-reserve picker to product order picking system. System’s performance in different operating scenarios tested with dynamic simulation and the significance of the most critical factors were measured with factorial design. Curcio and Longo [15] focused on inventory and internal logistics management problem within a specific supply chain node.

They aimed to monitor the performance of different inventory control policies under different working scenarios and to reduce the internal logistics cost by investigating the effect of such critical parameters: the number of suppliers’ trucks per day, the number of retailers’ trucks per day, the number of forklift, the number of lift trucks and the number of shelves levels. They adopted full factorial experimental design for the analysis. Hussain [16] quantified the effects of design parameters, that are information enrichment percentage, time to adjust inventory, time to adjust WIP, production delay and time to average sales on the bullwhip effect and dynamic responses produced on a multi-stage supply chain by sharing information with Taguchi's test method. Cannella, et al., [16] investigated the inventory and order flow dynamics in closed loop supply chain management, which is a complicated process. The effects of some reverse logistics factors, which are return rate, remanufacturing lead-time, number of echelons and information transparency, analyzed with DOE. According to the results, as the percentage of recollected items increases, the performance of the SC improves, while the remanufacturing lead-time increases, the performance of the SC is adversely affected. Chackelson, et al., [18] integrated a discrete event simulation with a DOE approach for a new order-picking design requirement in a warehouse. The impact of the lines per order, order commonality, routing, storage strategy, and batching on two responses, which were order maturity time and total picking time, was investigated using 2^k factorial design on Minitab software.

In the literature survey presented above, it has been observed that there are DOE approaches for different applications in logistics, but there is no study regarding to packaging and box selection problem. However, some studies without DOE method have been found for analyzing the strength of the box. One of these, which belongs to Hung, et al., [19], evaluated the relationship between water vapor and compression strength of three types of corrugated cardboard boxes. Experiments were carried out at constant temperature and 95% relative humidity using a bursting and compression test machine. The results presented that humidity affected the moisture content of corrugated cardboard box. In the Carstens's patent study [20], the horizontal edges of the box were drilled and the vertical edges were chemically treated to increase the compressive strength of the corrugated cardboard box. After the combination of mechanical and chemical treatments, the compression strength increased compared to the individual treatments.

The strength of the corrugated cardboard box, which is used frequently in logistics sector, is related with the type of paper, the weight of paper and the structure of box. The strength increases as paper quality or weight increases. However, there are other indirect factors that affect the strength of the corrugated cardboard box. In this paper, we analyzed the interactions between the strength of the corrugated cardboard box and some indirect factors, which are thickness of the box, the temperature and the humidity using design of experiment approach. Daily box production test values, daily temperature values and the humidity values of the 16 months schedule were considered for the analysis. The main contribution of this study is to consider the box strength problem in packaging, which is one of the titles of logistics sector, by using design of experiment method.

3. EXPERIMENTAL METHOD

DOE is a powerful procedure, which helps to investigate the effects of factors (input variables) on a response (output variable). Factorial designs are more efficient type of experiments to deal with several factors together instead of one at a time. Therefore, by a factorial design, all possible combinations of the levels of the factors are investigated in each complete replication of the experiment. The effect of a factor is defined to be the change in response produced by a change in the level of factors and called as "main effect". If the change in response between the levels of one factor is not same at all levels of the other factors, it means that there is an "interaction" between the factors [21]. In this study, 3^3 full factorial design approach, which is a factorial arrangement with 3 factors, each at three levels [22], was performed to investigate the effects of some factors on the strength of the corrugated cardboard box, that is used in a Glassware Company operating in Turkey. The critical factors taken into consideration were:

- thickness of the box,
- the temperature,
- the humidity.

The Glassware Company discussed in this study, uses BC wave type corrugated cardboard box with different dimensions in its logistics operations. This type of cardboard box is produced by physical and chemical processing of 5 different types of paper. Figure 2 explains a sample cardboard pattern.

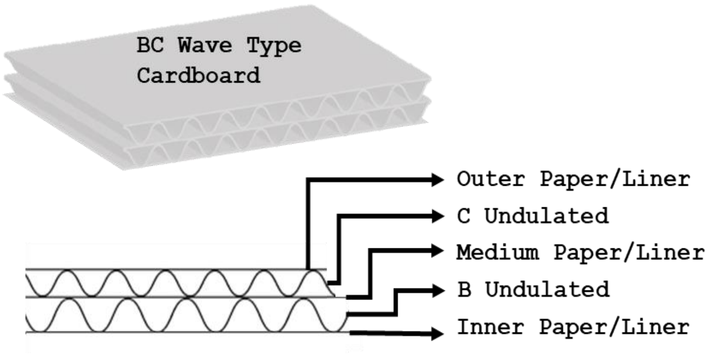

Figure 2. BC Wave Type Cardboard

In real life, each paper has different raw materials and weights (g/cm²). In this study, experimental data belonged to the standard cardboard boxes with the characteristics shown in Table 1 in order to keep the weights and paper types constant.

Table 1. The characteristics of the cardboard box used in the experiments of this study

	Box Characteristics				
	Outer Liner	C Undulated	Medium Liner	B Undulated	Inner Liner
Unit Weight(Gr/cm^2)	115	80	80	80	115
Paper Type	Kraft	Straw	Straw	Straw	Kraft

The proposed full factorial design replicated twice and 3^3x2=54 treatment combinations were performed randomly along with the levels of the three factors, which were presented in Table 2. The levels of the factors were denoted as low (-1), intermediate (0) and high (1).

Table 2. Factors and their levels

		Values		
Factor	Number of Levels	Low (-1)	Intermediate (0)	High (1)
Thickness (mm)	3	6.3	6.5	6.7
Temperature (^{0}C)	3	9	17	25
Humidity (g/m^3)	3	70	80	90

Within the scope of the experiments, compression test results were measured and recorded for each of the treatment combination. Figure 3 shows the working logic of the Box Compression Test (BCT). In the test, pneumatic rods move to compression plates up and down and a preset load is applied on the corrugated cardboard box until the first deformation on the cardboard box occurs. This determines how the box will respond when stacked. Then, the maximum load amount at which the deformation is first observed is recorded.

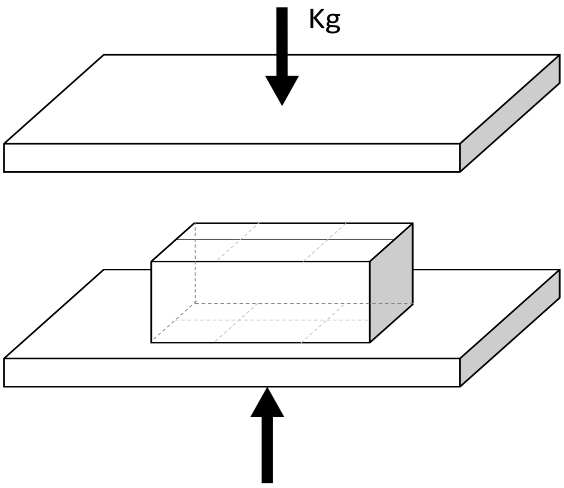

Figure 3. Box Compression Test (BCT)

Table 3 shows the maximum load (kg) results obtained in a box compression test with a total of 57 treatments performed randomly, depending on the thickness of the box, the temperature and the humidity values at different levels.

Table 3. Box Compression Test results of 57 treatments with different factor levels

Humidity (g/m³)		%70			%80			%90		
Template (⁰C)		9	17	25	9	17	25	9	17	25
Thickness (mm)	6.3	288.5	289.5	258	290.1	305.6	239.5	318.4	247	270
		289	284	226.5	314.5	317.5	249	312.8	253	307
	6.5	250	317	317.5	287.5	320	294	277	307.5	324
		300	322.5	311	288.5	312	292.5	262	300	305.5
	5.7	267.5	325.6	285	294	346	297	292	326	320
		276	320.5	315	271	348.5	285.6	298	297	355

4. RESULTS AND DISCUSSION

The obtained results from box compression test were then analyzed on Minitab software (version 17, Minitab Inc., State College, PA) using ANOVA test. Figure 4 shows the four-in-one residual plot (i.e. normal probability plot of residuals, histogram of residuals, residuals versus fitted values and residuals versus order of the data) for maximum load value that was taken as response. Residuals are used in regression and ANOVA analyses to indicate how well our model fits the data. Results indicate that the data are linear, random scattered and the histogram is symmetric bell-shaped. The residuals versus order exhibit no clear pattern. Therefore, it can be said that the data are consistent with normality, independence and the assumption of constant variance is valid. In light of these, the experimental design is acceptable.

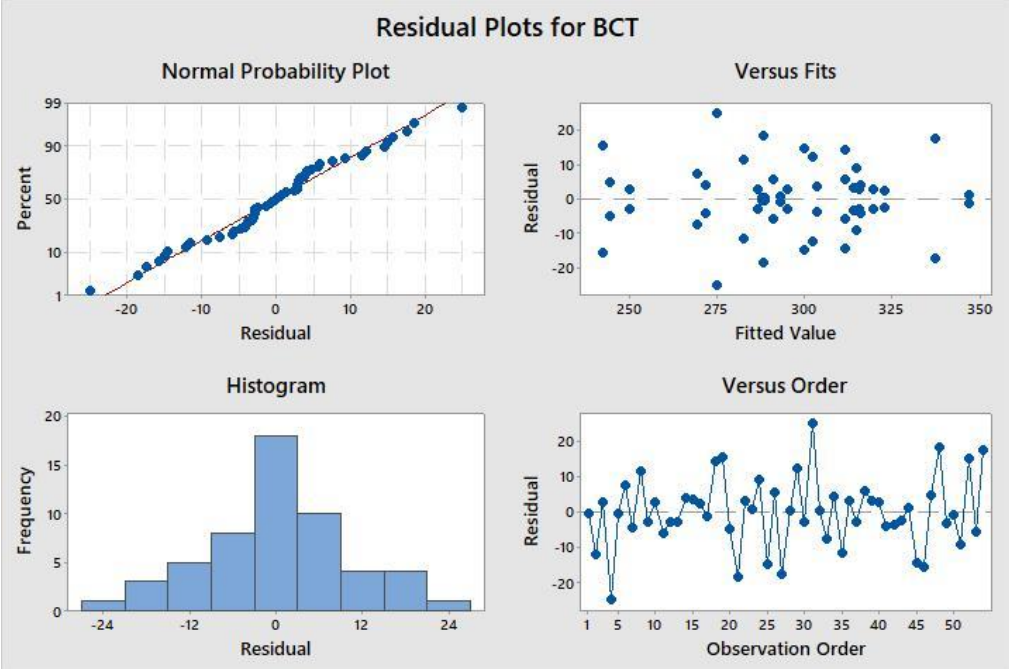

Figure 4. Residual Plots for maximum loads that were obtained as results of BCT

Figure 5 presents the plots of residuals versus each factor. The plots reveal that there is much less scatter in the residuals at the intermediate value of humidity and temperature.

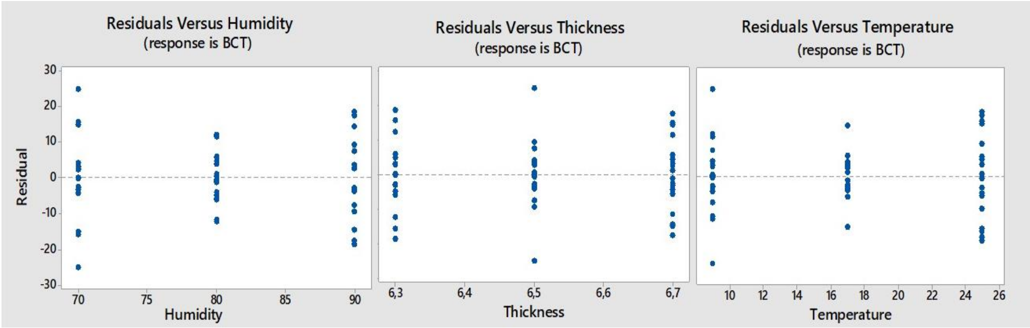

Figure 5. Residuals versus each factor

In order to see the effects of factors on maximum load value of a corrugated cardboard box, main effects plot which is given in Figure 6 was drawn. It is clearly evident that, higher thickness values have positive effect on the strength of corrugated cardboard box. When the humidity values are taken into account, it is seen that the increased humidity values also increase the strength even if just a bit. On the other hand, the strength of the corrugated cardboard box only increases when the temperature is 17^{0}C.

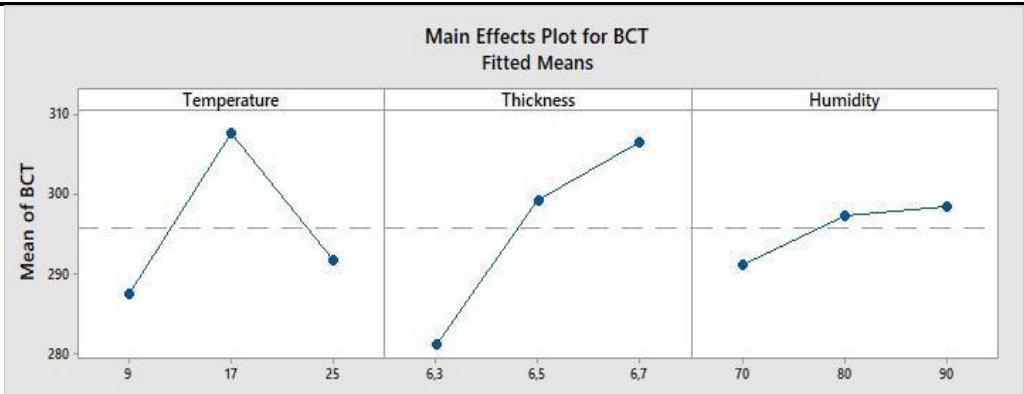

Figure 6. Main effects plot

Figure 7 examines the interactions between factors. If there are parallel lines on plot, this means that there is no interaction effect between the factors. However, in our experiment, interactions are more significant. The strength of the corrugated cardboard box is higher when the humidity is 80g/m^3 and the thickness values are 6.3mm and 6.5mm. But, when the thickness is 6.7mm, the corrugated cardboard box has a lower strength when humidity is 80g/m^3. In addition, when the thickness is 6.3mm, the temperature and the strength of the corrugated cardboard box inversely affects each other. This means, as the temperature increases, the strength of the corrugated cardboard box decreases. Although we do say that the thickness and the humidity values have positive effects on the strength of corrugated cardboard box according to figure 6, the thickness and humidity interaction plot shows a different situation. For the humidity value of 70g/m^3, the strength of the box decreases when the thickness value changes from 6.5mm to 6.7mm. Similarly, in Figure 6 we have said that the best strength is obtained when the temperature is 17. When we look at the interaction between temperature and humidity, for the humidity value of 50g/m^3 and the strength of the box is higher at 9^{0}C and 25^{0}C than 17^{0}C.

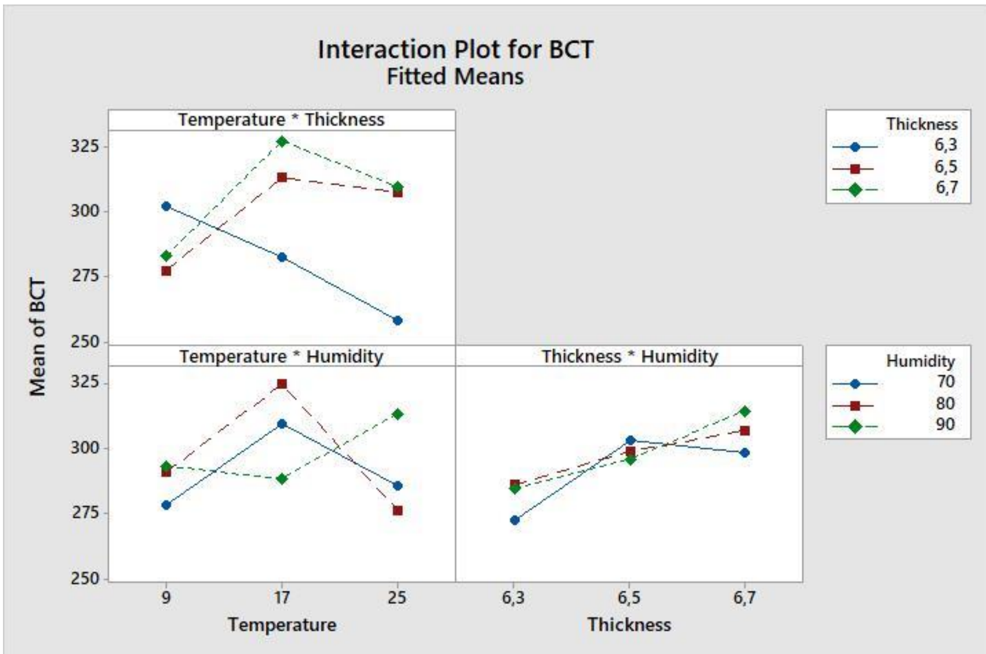

Figure 7. Interaction plot between the factors

5. CONCLUSION AND RECOMMENDATIONS

In logistics sector, the damage of products is usually caused by the lack of strength of the boxes in which the transportation operation is carried out. The type of cardboard paper, the weight of paper, the thickness of cardboard etc. are directly related with the strength of the cardboard box. However, there are other indirect factors that affect the durability. In this study, it was aimed to provide a solution to a Glassware Company operating in Istanbul for the costs caused by damage. For this purpose, the factors affecting the strength of the corrugated cardboard boxes used for logistics operations by company were analyzed by design of experiment (DOE) methodology. Firstly, the DOE approach was examined generally, and the literature review related to the DOE applications in logistics sectors was presented in detail. Then we stated a brief literature regarding to packaging and box selection problem and set out some critical factors that affect the strength of the box from previous studies. Three indirect factors, which are the thickness of the box, the temperature and the humidity, then were taken into consideration using 3^3 full factorial design approaches. 57 treatments were carried out randomly and box compression test results were obtained. According to the results, the discussed factors and the interactions of the factors were evaluated with the help of Minitab software. The analysis showed that when thickness and humidity factors are considered on their own, the strength of corrugated cardboard box increases as their value increases. On the other hand, the strength of the box only increases when the temperature is 17^0C. For this reason, it is necessary to take account of seasonal conditions in the cardboard box production process. However, since there is interaction between factors, it is difficult to reach definite conclusions. So, the case should be studied with detailed analysis and different parameters.

NOTICE

This study is presented at 05-08 September 2018, 3rd International Science Symposium (ISS2018) in Pristina-Kosovo.

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