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6. Telecommunication;
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CONTENT

The Appendix of the first number of Balkan Journal of Applied Mathematics and Informatics, is devoted to the reports of the First Modelling Week in Macedonia, which was held in Stip, 12-16 February 2018.

The First Modelling Week in Macedonia was organized by Faculty of Computer Science - Department of Mathematics and Statistics, Faculty of Electrical Engineering and Faculty of Technology with the support of the TD 1409 MI-NET Cost Action. The aims of the Modelling Week were: widening, broadening and sharing knowledge relevant to the Action's objectives through working on modern and actual problems which can be solved with mathematics and mathematical modelling.

The Modelling Week was organized under auspices of Prof. Blazo Boev, Rector of the Goce Delcev University, Stip, Macedonia.

The Program Committee of the First Modelling Week were:

1. Vineta Srebrenkoska, PhD – Macedonia
2. Tatjana Atanasova – Pachemska, PhD – Macedonia
3. Poul G. Hjorth, PhD – Denmark
4. Wojciech Okrasinski, PhD – Poland
5. Joerg Elzenbach, PhD – Germany
6. Gregoris Makrides, PhD – Cyprus
7. Biljana Jolevska – Tuneska, PhD – Macedonia
8. Limonka Koceva Lazarova, PhD - Macedonia

In the First Modelling Week in Macedonia participated 34 participants from Macedonia, Bulgaria, Portugal and Denmark. The Modelling Week was aimed towards Masters, PhD students, Early Career Investigators (up to 8 years after their PhD). All the participants were split in three groups in order to solve the three problems which were set:

Problem 1 - Scheduling in kindergarten, proposed by Limonka Koceva Lazarova

Problem 2 - Determining the optimal number of cash boxes to increase the efficiency of the customer service and determining the way of storage of products in the warehouse. How to manage stocks in the warehouse, proposed by Tatjana Atanasova – Pachemska.

Problem 3 - Optimization of the industrial processes for production of advanced polymer composites by implementation of the full factorial experimental design, proposed by Vineta Srebrenkoska.

The third problem was split in three subproblems.

All of the solutions are presented in form of reports in this appendix.

Thanks for the editors of the Balkan Journal of Applied Mathematics and Informatics, about their support for publishing of the results from The First Modelling Week in Macedonia.

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APPLICATION OF FACTORIAL EXPERIMENTAL DESIGN IN PREDICTING PROPERTIES OF POLYMER COMPOSITES

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Abstract: The purpose of the study is to access the applicability of full factorial experimental design in predicting properties of polymer composites. The preparation of the composites was conducted by applying 2^2 full factorial experimental design. The fiber/resin ratio was taken to be the first factor and the second – mixing temperature. For the first factor, low and high levels are chosen to be 20/80 and 40/60, respectively and for the second factor – 175°C and 195°C, respectively. For composites the tensile and flexural strengths were determined in a lab. On the basis of the received experimental data it was created the regression equitation which the best describes the process.

Keywords: experimental design, polymer composites, regression equitation.

1. Introduction

More and more factors have an influence on effectiveness and efficiency in the industrial processes and systems. An important question of science is to identify the most important factors for controlling complex processes and systems, to know their levels and influences to control all things in a right manner.

To find the optimum in control of the processes there are often a lot of experiments to realize – practical and theoretical ones. In this field the sensitivity analysis as well as simulation and the design of experiments too are used. This is necessary to rapidly prevent failures and solve problems early. Design of experiments has an old tradition and history by R. Fisher, Taguchi, Shainin i.e. design of experiments is a structured, an established and an organized method of quality management. The key factor to minimize optimization costs is to realize as few experiments as possible. Design of experiments requires only a small set of experiments and thus helps to reduce costs. Design of experiments is used to determine the relationship between the different factors (xi) affecting a process and the output (result) of that process (y). Design of experiments has more to offer than a "one change at a time experimental method". "One change at a time experimental method" has always the risk that the researcher will find only the significant effect on the output. Design of experiments also focuses on dependency and interaction between the factors. Design of experiments plans for all possible dependencies at first, and then prescribes exactly which data are needed to assess them. The exact length and size of the experiment are set by the experimental design before the real experiments begin [1].

Design of Experiments involves designing a set of experiments, in which all relevant factors are varied systematically (Fig. 1). When the results of these experiments are analyzed, they help to identify optimal conditions. Further results of design of experiments are:

- The factors that most influence the results (high effect).
- The factors that little influence the results (small effect).
- The existence of interactions and synergies between factors.

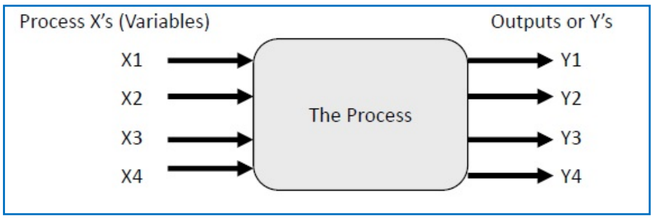

Figure 1. Model of design of experiments

The common way to use design of experiments is the following:
- Define the objective of the investigation.
- Define the variables (factors) *yk* that will be measured to describe the output.
- Define the variables (factors) that will be controlled xi during the experiment.
- Define the ranges of variation and the factor levels of each factor.
- Define and optimise the experimental plan.
- Prepare and carry out the experiments carefully and secure the results [2].

2. Experiment

The composite pipes were produced based on polypropylene as a matrix and natural fibers as reinforcement. Polypropylene based composites were taken in this study because of the cost favorability compared to high performance fiber composites. The preparation of the composites has been performed by melt mixing, in a Brabender-like apparatus (Haake Rheocord, New Jersey, USA).

The obtained composites were cut into pellets to produce sheets for further characterization.

During the preparation of the composites, several factors were observed: polymer viscosity, mixing temperature, fiber/polymer content etc.

There are lot of factors that influence the process, but there are only two important that have a big influence on the output which we have used in the experimental design:
- fiber/resin ratio (factor 1),
- mixing temperature (factor 2).

Next step was determination of the factor levels as shown in the Table 1, namely for the first factor the low and high levels are set at 20 wt% and 40wt% fiber content, respectively, second factor – at 175ºC and 195ºC, respectively. Each factor has two factor levels, a low one and a high one. The low one has the value of (-1), the high one has a value of (+1). There are two factor levels with p = 2 and four combinations (N= 4):

$$N = p^k = 2^2 = 4 \quad (1)$$

Where:

N = combinations; k = factors; p = factor levels.

For the statistical analysis five tests of each combination were realized so the number of replications is twofive. With that assumption, we have taken the first-order linear model with interactions to predict the response function, i.e. the mechanical properties of the composites within the study domain (20/80 – 40/60) ratio x (175-195) ºC.

The full factorial experimental design allows making mathematical modeling of the investigated process in a study domain in the vicinity of a chosen experimental point [3, 4]. In order to include the whole study domain, we have chosen the central points of both ranges to be experimental points. For the fiber content of the composites we have chosen the experimental point to be 30 wt%, and for the kneading temperature the experimental point – 185 ºC (which corresponds to previously defined levels).

Table 1: Factor levels

Code	p = 2	(-1)	(+1)
x_1	Fiber content wt. %	20	40
x_2	Mixing temperature (ºC)	175	195

The samples for mechanical testing were fabricated by compression molding. The pellets obtained after melt mixing were put in a molding frame with desired dimensions and have been molded by thermo-compression, with increasing pressure up to 4500 Pa. After the expiration of the heating time, the press was cooled by circulating cold water. From all composites plates with thickness 3 mm were produced.

The obtained composites have been characterized by flexural and tensile tests. The tensile testing was performed according to ASTM D 638-99 standard on a Instron Universal Machine Model 4301 using unnotched samples while the flexural testing was conducted according to ASTM D 790 standard using three point flexural sharply notched samples. The tests were performed at crosshead speed of 2mm/min, at room temperature. Each result obtained represents the average of five samples.

3. Results and discussion

The test results (flexural and tensile properties) for the polypropylene based composites are presented in Table 2 together with the experimental matrix.

Table 2. Experimental matrix with results

Trials	x_1	x_2	$x_1 x_2$	*Tensile test*		*Flexural test*	
				Stress at peak, MPa	*Modulus, MPa*	*Stress at peak, MPa*	*Modulus, MPa*
1	-1	-1	+1	26,7	2875	42,6	1941
2	+1	-1	-1	36,8	2881	48,5	2575
3	-1	+1	-1	33,9	3034	44,8	1884
4	+1	+1	+1	42,4	2416	51,8	2531
-1 Level	20	175					
+1 Level	40	195					

By implementing the 2^2 full factorial experimental design, it was found that response functions for flexural (y_{fk}) and tensile strength (y_{tk}) with coded variables, are

$$y_{tk} = 34.95 + 4.65x_1 + 3.2x_2 - 0.4x_1x_2 \quad (2)$$

$$y_{fk} = 46.925 + 3.225x_1 + 1.375x_2 + 0.275x_1x_2 \quad (3)$$

and in engineering or natural variables, y_{fn} *and* y_{tn}:

$$y_{tn} = -38.2 + 0.465x_1 + 0.32x_2 \quad (4)$$

$$y_{fn} = 11.8125 + 0.3225x_1 + 0.1375x_2 \quad (5)$$

In the full factorial experimental design the term x_1x_2 is the interaction between factors which also might have influence on the response, in our case stress at peak values for tensile and flexural tests.

Analyzing the regression equations it can be found out that the main positive contribution to the mechanical characteristics is given by the fiber content of the composites i.e. tensile and flexural strength are directly proportional to the fiber content of the composites. On the other hand, the mixing temperature of the composites has lower positive effect on strengths. The interaction of the two factors, for the tensile and flexural tests, with coefficient of -0,4 and +0, 275 respectively to the tensile and flexural tests, has a negligible negative and positive effect on the response which is of secondary order compared to the influence of fiber content and mixing temperature. So, the interaction of the two factors can be omitted in the regression equations with engineering variables.

The overall results for the mechanical properties of polymer composites based on polypropylene reinforced with kenaf fibers are presented in Table 2. The increased fiber content in the composites results in higher flexural modulus. Obviously, at higher fiber content, the interfacial area between the fiber and the polymer also increases which results in increase of the interfacial bonding between the kenaf fibers and polypropylene. For regular shape reinforcements, the strength of the composites increases due to the reinforcement to support stress transfer from the polymer matrix [5, 6].

Based on the obtained regression equations in engineering or natural variables we could do the design of composites. So, for a given request for tensile or flexural strengths, by substitution of y_{fn} *and* y_{tn}, in the equations (4) and (5), the fiber content of the composites can be calculated and then the appropriate fiber/matrix ratio will be used in fabrication of the composites. Also, y_{fn} *and* y_{tn} i.e. values of tensile or flexural strengths, can be calculated for a given fiber content (x_1 factor). In both above cases the mixing temperature has to be fixed at 185°C for the most favorable outcome.

4. Conclusion

In the frame of this paper full factorial experimental design was applied to predict the mechanical properties of the polymer composites. The important entries that influence on the improved solution were defined. For the range of the mixing temperature and fiber/resin ratio the experimental measurements of the tensile and flexure strength of composite pipes were carried out by implementing the 2^2 full factorial experimental design. A correlation equations were established for tensile and flexure strength as a function of the fiber content and mixing temperature and of the interaction between them. Namely, it was created the regression equitation which the best describes the process. It was observed that if the study domain is precisely established (narrow enough), the factorial experimental design can be employed in order to give good approximation of the response. It was made verification of the model i.e. the adequacy of the regression equation and it was found that the model is adequate and can be accepted and further used.

Acknowledgment

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