CORRELATION BETWEEN PRODUCTION'S PROCESS PARAMETERS OF GLASS-FIBER BASED COMPOSITE MATERIALS WITH ITS MECHANICAL PROPERTIES

Atanas Kocov[1], Dijana Spaseska[2] and Jovan Lazarev[1]

[1]Faculty of Mechanical Engineering, University "St.Kiril and Metodij", P.box 464, 1000 Skopje, Macedonia
[2]Faculty for Technology and Metallurgy, University "St.Kiril and Metodij" P.box 580, 1000 Skopje, Macedonia

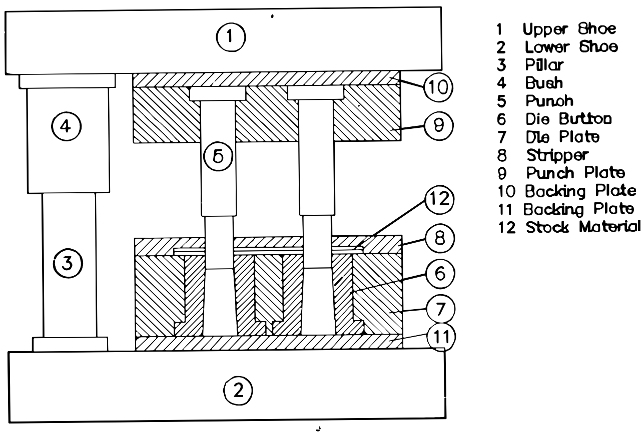
ABSTRACT

This paper outlines mathematical design of the production's process of glass fibers reinforced composite material. The new developed composite is used for designing progressive press tools. The mathematical model has been defined by using experimental planning method. The correlation between the composite production process's parameters and the mechanical properties or responses of the composite, as well as its compositions, was the main point of the mathematical treatment and optimization of the composite based on glass fiber. The corresponding response surface equations are calculated by means of the multivariable analysis technique.

The purpose of the investigation is to analyze the correspondence of the use of the composite material as a constructive material in metal forming tool design.

1. INTRODUCTION

Progressive press tools are used for producing a wide range of products, which vary from high-precision components in electrical appliances to the body of a car [6]. The design of press tools is a complex and highly specialized procedure. The diverse nature of products produced by press tools demands a high level of knowledge on the part of the designer that can be achieved through years of practical experience.

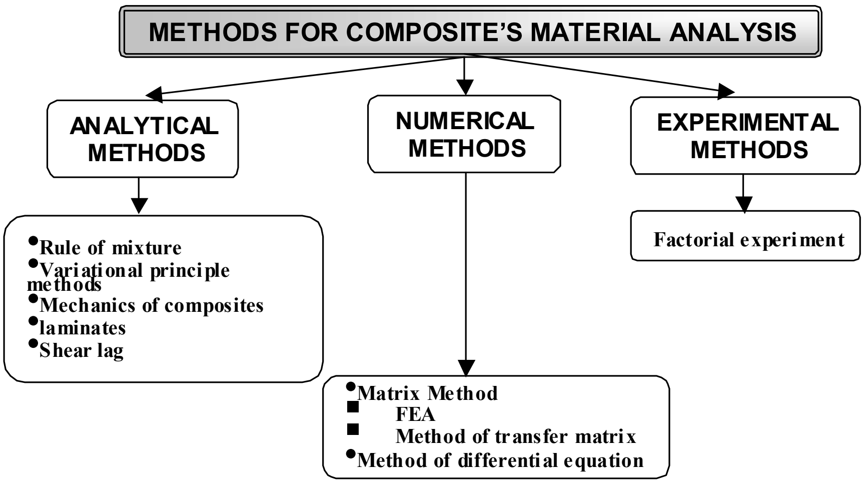


"**Fig.1.** General layout of a press tool"

The tool consists of the groups of components, as shown in Fig.1. The first comprises ounches die buttons, punch and die button shoes, pillars, bushes and fasteners, which are industry standard components that can be ordered in standard sizes. The second group comprises special punches, punch and die button plates, backing plates and strippers, which are different for each product.

Mostly used material for designing press tools are conventional materials: metals and metal alloys. Also, there are epoxy resin tools, which have been used for explosive forming, stretch blocks, rubber bed press tools, drop-hammer punches and dies, and dies for press forming [4]. The construction of resin metal forming tools such as punch and die sets usually

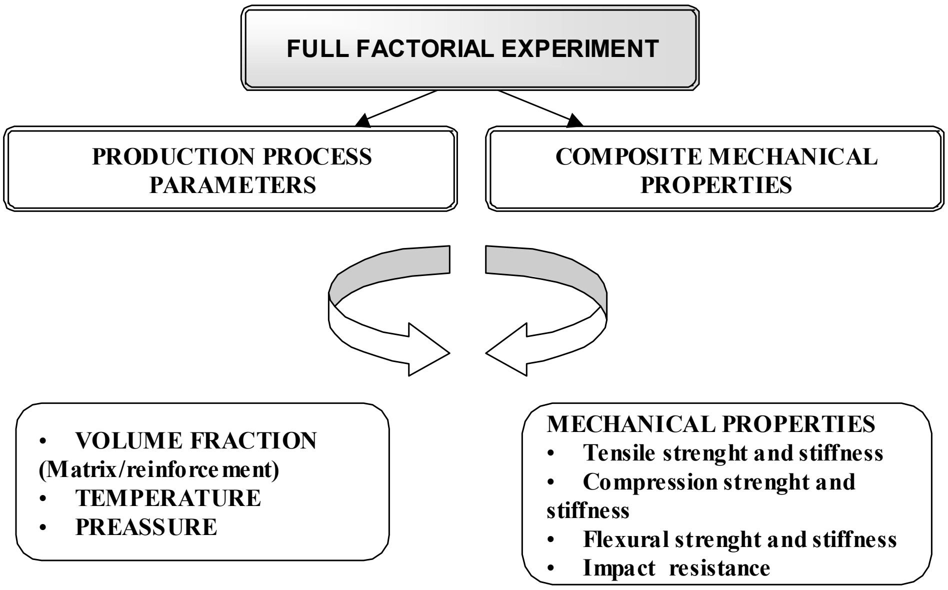
employs a low cost rigid or faced with a high quality resin system. Alternatively, a resin face can be cast on to an existing metal punch. The compressive strength, impact strength and surface hardness of the resin system are clearly of great importance for these applications.
The material selection process for metal forming tool's design is a complex process, which includes understanding and determining the requirements, selection of possible materials, determination of candidate materials, testing and evaluation. It is especially important for metal forming tool's design where some requirements are critical to the application, as it is the weight, or wear resistance may not be of concern. There is no standard technique used by the designer to select a right material for an application. The idea of using composite materials as a constructive material for metal forming tools is relatively new [10,11] and this paper outlines some experimental and numerical methods for developing and analyzing composite material applicable as a constructive material for metal forming tool design.
Some of the methods for analysis, which could help to select the right composite material, are shown in Fig.2.



"**Fig.2.** Methods for analysis of Composite material's properties"

2. EXPERIMENTAL PROCEDURE

The glass woven/epoxy composite has been developed and experimentally treated by using three factorial full planed experiment. Using experimental planning method, the mathematical model has been created. The main aim is to define the optimal matrix-reinforcing material relation and to produce the material with high performances and possibilities to be implemented as a constructive material.
The experimental procedure and full factorial experiment allows defining and setting the correlation between the composite production process's parameters and the mechanical properties or responses of the composite, as well as its compositions. The three factorial experiments have been used to correlate the technological production process's parameters with the composite's mechanical characteristics for defining the optimal composite material's parameters, as it is shown in Fig.3.



"**Fig.3.** Correlation between production process parameters and mechanical properties "

A well-designed factorial experiment can substantially reduce the number of required experiments. A design consisting of eighth experiments has been used to develop the model for defining the correlation between the composite material production's process parameters and mechanical characteristics of the composite. The levels of experimental investigations and parameter level changes are presented in Table 1.

"**Table 1.** Full three-factorial experiment for determination of the correlation between the production process's parameters and mechanical characteristics of the composite material"

No. of the experiment	*Matrix of the experiment plan's*								*Characteristics (experiment's conditions)*		
	x_0	x_1	x_2	x_3	$x_1 x_2$	$x_2 x_3$	$x_1 x_3$	$x_1 x_2 x_3$	x_1(%)	x_2(^{0}C)	x_3(MRa)
1	+1	-1	-1	-1	+1	+1	+1	-1	40	150	4
2	+1	+1	-1	-1	-1	+1	-1	+1	60	150	4
3	+1	-1	+1	-1	-1	-1	+1	+1	40	170	4
4	+1	+1	+1	-1	+1	-1	-1	-1	60	170	4
5	+1	-1	-1	+1	+1	-1	-1	+1	40	150	6
6	+1	+1	-1	+1	-1	-1	+1	-1	60	150	6
7	+1	-1	+1	+1	-1	+1	-1	-1	40	170	6
8	+1	+1	+1	+1	+1	+1	+1	+1	60	170	6
Basic level		50	160	5							
Variation interval		10	10	1							
Upper level		60	170	6							
Lower level		40	150	4							

The mathematical model has been established and the functional relationship between response of the composite:

- ➢ Ultimate tensile strength and tensile modulus,
- ➢ Ultimate compression strength and modulus,
- ➢ Impact resistance,
- ➢ Flexural strength and modulus

and the investigated independent variables, the technological production process parameters:

- ➢ Glass/resin relationship, noted X_1, [40-60 %]
- ➢ Deformation temperature, noted X_2, [150-170 ^{o}C] and
- ➢ Deformation pressure, noted X_3 [4-6 Bar]

Could be presented by polynomial models, as shown in Eq.1, for each mechanical characteristic.

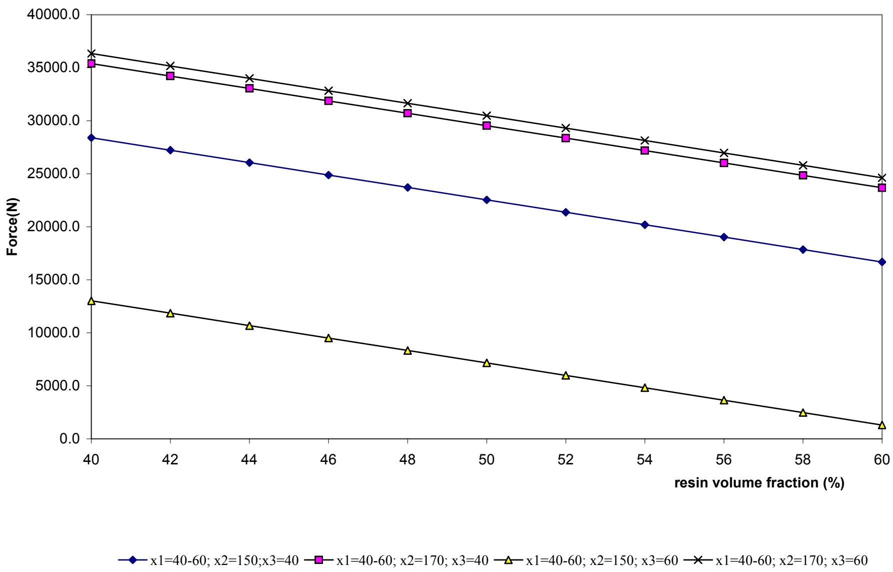
The corresponding response surface equations are calculated by means of the multivariable analysis technique. In the mathematical model, given in a canonical form by polynomial equation:

$$Y(x)=-434537.75+8143.06X_1+3083.72X_2+7623.07X_3-55.67X_1X_2-137.56X_1X_3-49.95X_2X_3+0.89X_1X_2X_3 \quad (1)$$

The statically determination of the coefficients was verified with Student criterion and the adequacy of the regression equation was checked with Fisher criterion and proves the adequacy of the model. Namely, the equation presents what is the influence of the parameters on the mechanical properties of the composite material

Since, the objective is designing of a material, which will substitute metal and metal alloys in metal forming tool's design; the experimental procedure is directed to the investigation and determination of the strength and stiffness of the composite material when the applied load is impact, pressure, tensile or flexural. These loads mostly appear in the metal forming tool during the tool exploitation. The applied experimental investigations define the mathematical models for strength characteristics of the material as a function of technological production process's parameters. The equations in canonical way present the composite mechanical properties.

Standard test methods have been used for determination of mechanical properties of the composite material. The tensile test, three point bending test, compressive test and impact test have been used for determination of the strength and stiffness of the composite material. All the tests are done by using 3 and 10 mm thick specimens, according ASTM standard tests methods, in transversal and longitudinal direction of the fiber orientation.

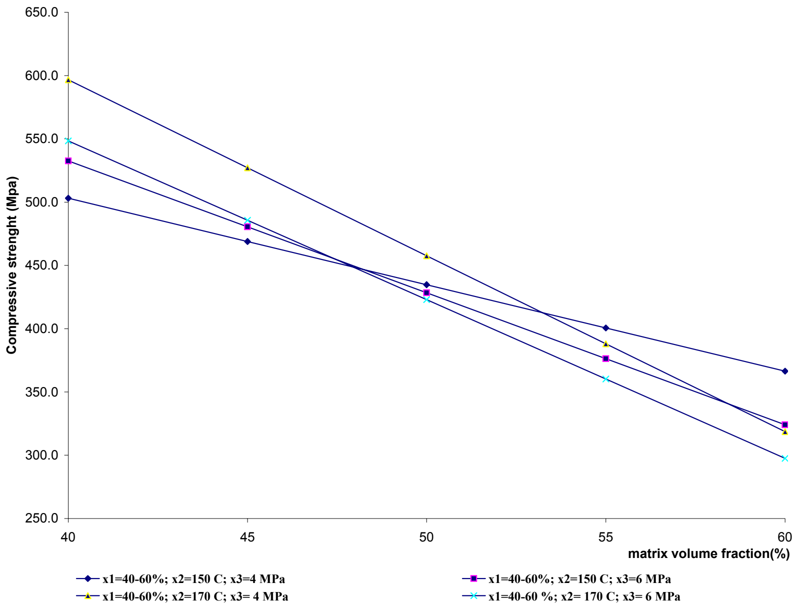


"**Fig.4.** Tensile force vs matrix volume fraction"

For example the tensile force as a function of production process parameters could be presented in polynomial form, as shown in Eq.2.

$$Y(x) = -141336.098-585.9844X_1+1166.3438X_2+3517.2032X_3-20.4109X_2X_3 \quad (2)$$

The tensile force versus resin volume fraction is shown in Fig.4. The tensile strength of the composite material decreases with the increase of the resin volume fraction. The optimal value of the resin volume fraction could be determined by comparing all of the mechanical properties and needs for metal forming tool's design according the Eq.2.



"Fig.5. Compressive strength vs production process parameters"

The negative influence of the raise of the resin volume fraction in the composite volume, and positive influence of the temperature and pressure as technological process parameters is demonstrated in Fig.5.

The influence of the technological production process parameters to the compressive strength and stiffness could be expressed and discussed by the polynomial regression equations.

For example the regression equation with coded variables for the compressive strength is as following:

$$f(x)=444.21-107.5x_1+4.85x_2-8.62x_3-22.8x_1x_2-5.24\,x_1x_3-6.97\,x_2x_3+12.41x_1x_2x_3 \quad (4)$$

or the regression equation with natural variables:

$$y(x)=-6540.4+127.8x_1+44.4x_2+112.3x_3-0.85x_1x_2-2.04\,x_1x_3-0.7\,x_2x_3+0.012x_1x_2x_3 \quad (5)$$

By using above-mentioned polynomial equations Eq.4.and Eq.5., the composite engineer could determine and define mechanical properties, composite's strength and stiffness by variation of the technological production process parameters. It makes easier way to create material with mechanical characteristics, which are important to be reach for composite implementation in tool design.

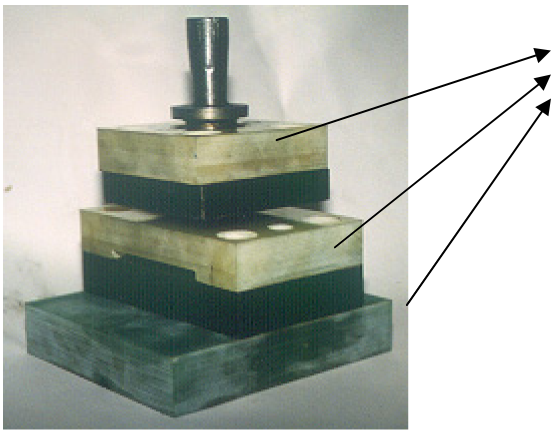
The eight level factorial experiment carried out that the optimal reinforce material volume fraction is 60-65%, temperature of pressing: 170^{o}C and 4 MPa pressure of pressing. The final mechanical properties of the designed composite material which was a subject of this research are shown in the following Table 2.

"Table 2. Mechanical properties of the produced composite material"

Resin: epoxy	
Filler: woven glass	
Characteristics: Mechanical properties:	
Cross breaking strength:	556 MPa
Impact resistance-Charpy method	200 KJ/m2
Compressive strength	424 MPa
Shear strength	140 MPa
Tensile strength	516 MPa
Flexural module	18 GP

3. NUMERICAL ANALYSIS

The real model has been designed with the upper and lower shoe made from composite material, as well as the stripper, as shown in Fig.6. The real model has been experimentally and numerical tested. Namely, the experimental tests involves strain gages for measuring in real conditions - tool mounted in the press and its usage, and stress and other analysis, which have to be performed to evaluate the design concept, are done by using Finite element analysis software.

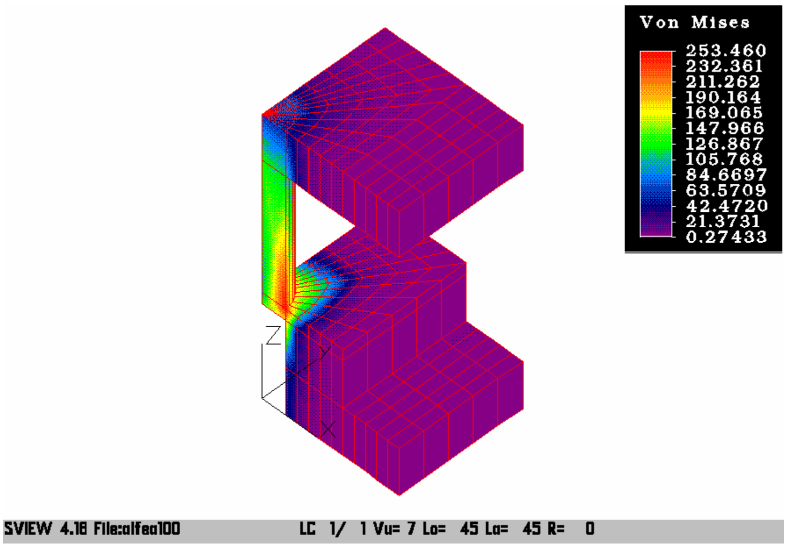


Composite plates

"Fig.6. Punching metal forming tool"

The numerical model is designed and discretizied with finite elements by using ALGOR-FEA, software. A serial of numerical analysis has been carried out to investigate the carrying capacity and strength of the upper and lower shoe by changing the thickness of the punched material (s=1, 2 and 3 mm); the punch diameter (d=20, 22 and 24 mm) as well as the shoe's thickness (t=20, 22 and 24 mm). The idea is to analyze different thickness because of the analysis of the geometry of the tool. The most important thing is not to destroy the geometry of the tool during its use. The axis of all tool parts should stay collinear during the tool exploitation, how the tool damage would not happen. The most possible damage could be

happened because of the low hardness of the composite upper and lower shoe, and other metal tool parts could be imbedded into the composite parts.
Some of the distribution of the effective stress through the punch and the upper shoe of the tool are shown in Fig.7.



"Fig. 7. Stress distribution through the metal forming tool"

The stress distribution in lower composite shoe plate compared with the stress distribution in the metal plate (low carbon constructive steel) is shown on Fig.8. The diagram shows that the distribution of the stress in the composite plate is in the range as for the metal one in the case of lower shoe's examination on flexural loads.

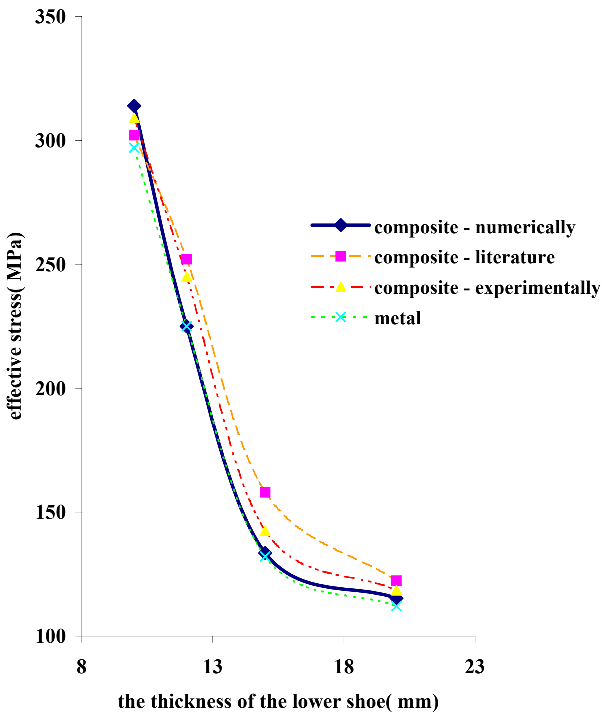


Fig. 8. Comparison of the stress distribution for analytical, numerical and experimental analysis

The distributions of the stresses for upper and lower tool's shoe, show that the effective stress distributed through the tool are not high than the composite material ultimate strength and stiffness, which means that the geometry of the tool will remain during the tool usage. This means that the composite plates will satisfy needs for the tool geometry. Namely, all of the numerical analysis proved the strength and stiffness of the composite used for press tools. The results show that good improvement has been reached for the compressive strength, impact strength and the surface hardness of the composite system, which have been defined by experimental procedure and which are clearly of great importance for metal forming tools.

4. CONCLUSIONS

The experimental and numerical analysis, which were carried out for this work, could proved that the composite material offers several advantages over traditional engineering materials used for metal forming tool's design. Some of these advantages are as following:

- Composite material provide capabilities for part integration, and metallic components could be replaced by a single composite plate
- Composite material has a high specific strength and stiffness (strength and stiffness – to density ratio; high fatigue strength and corrosion resistance;
- Composite material offers increased amount of design flexibility, which is mostly important for metal forming tool's design where a complex structure, parts and special contours of the tool are present. It means composite offers greater manufacturing feasibility especially for designing metal forming tools for producing automotive part.

Namely, with experimentally treatment of the composite material, the correlation between the production parameters and the mechanical properties are established. The experimental procedure for defining composite material's properties gives an opportunity to the tool's designer to reach the mechanical properties of the composite material to satisfy the tool's working parameters.

From the other side this investigations which have been performed, lead to the new tools design with material which has low specific weight associated with strength, stiffness, fatigue and wear resistance and high specific strength and stiffness which are important for the geometry of the tool. The new designed tool has lower mass, and it is easier and simpler mechanical tool's design operations. The most important is the possibility to use composite materials to design large metal forming tools for an example for bending and drawing parts for automotive industry, where the tool mass is much higher if the tool is made by using metal and metal alloys. The further investigation will be directed in the field of above mentioned metal forming tool design.

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