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Research Article

Influence of Process conditions on Tensile Properties of Chicken Feather Fibre Reinforced with Polypropylene Composite Board

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Abstract

Chicken feather fibre reinforced composite board was manufactured through the stacking technique using the compression moulding machine.The aim of the research work is to use cheap and profuse chicken feather fibre, to investigate and optimize the process variables related to the tensile strength of chicken feather fibre reinforced with polypropylene composite board. The composites were produced according to a central composite design, proposed by Box and Behnken with three independent variables namely, pressure, temperature and time at three levels each. The effect of temperature, pressure and time with respect to the tensile strength property of chicken feather fibre composite has been analyzed and Minitab 15 version software used to optimize the process variables. The composite boards were subjected to tensile strength tests and the fractured surfaces were observed under scanning electron microscope as declared. The scanning electron microscope photographs of the fractured surfaces of the composite board showed diverse extents of fibre pull-outs under tensile failure form. The best tensile properties were observed if the composite board is manufactured using high temperature (185°C) and pressure (15 bar). For tensile strength the time doesn't play a significant role. The actual values of tensile strength are in good concurrence with predicted values, the correlation coefficient is found to be 96%.

Keywords: Chicken feather fibre; Polypropylene; Box-Behnken method; Compression moulded composite; Tensile strength.

Introduction

Natural fibres exhibit many advantageous properties; they are a low-density material yielding relatively lightweight composites with high specific properties. These fibres also have significant cost advantages and ease of processing along with being a highly renewable resource. It also reduces the dependency on foreign and domestic petroleum oil. Recent advances in the use of natural fibres (e.g., cellulose, jute, straw, switch grass, kenaf, coir and bamboo) in composites have been reviewed by several authors [1-2].

Natural fibres are used as suitable reinforcing material to satisfy environmental aspects, and they are now rapidly emerging as a potential alternative to synthetic fibres in engineering composites [3]. A composite containing at least one constituent (e.g., matrix or reinforcement) that is derived from readily renewable resources may be considered a bio-composite [4].

Owing to environmental awareness and reduction of petroleum oil, bio-plastics and their composites are one of the most researchable topics throughout the world. Polymers that are produced from renewable sources are expected to be the best alternative to replace conventional polymers. Constrain of these bio-plastics is its cost which limits its application in certain purposes. Bio-plastics filled or reinforced with natural fibres can reduce cost and improve properties, like stiffness, strength and toughness of bio-composites [5].

The unlimited source of high performance materials in nature has to be seriously studied to establish them as basis for novel technologies and valuable raw materials. One among this is keratin fibre from chicken feathers. Nearly three billion pounds of chicken

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feathers are wasted in India annually. These feathers pose an environmental challenge. In order to find a commercial application of these otherwise wasted feathers, composites have been prepared from feathers. It was found that voids and density of composites have effect on mechanical properties [6].

Keratin, considered as the main structural element of these materials, contributes to a wide range of essential functions, including temperature control and physical and chemical protection. Structural studies of hair fibres, including wool, reveal highly organized subcomponents. These subcomponents in feather fibres starting from their complex branched structure of keratinaceous filaments. The keratinaceous grow by a unique mechanism from cylindrical feather follicles. This branching structure, a distinctive morphological feature of feathers and has its origin in the biological evolution of feathers [7]. Chicken feather fibre has a few hydrophobic side chains. The moisture regain of Feather fibre is about 9.7%. Barbs have strength of 1.44 g / den, elongation of 7.7%, and modulus of 35.6 g /den [8].

Thermoplastic resins that can be processed below 200°C, should be selected for processing of composites. The most commonly used thermoplastic in polymer matrices with relevant contribution to the world economy. Polypropylene is the one of the cheapest and has excellent toughness and impact strength, but the lowest in service temperature [9]. Polypropylene is also very suitable for filling, reinforcing, and blending. Polypropylene with fibrous natural fibres is one of the potential routes to create natural synthetic polymer composites [10-11]. The mechanical properties of keratin materials/PP composites depend not only on the strength of adhesion, but also on the conditions of processing [12]. The fibre–matrix interface adhesion are mainly depends on voids and the bonding strength at the interface. In order to characterize the fibre matrix interphase, micromechanical methods which specifically probe the interfacial strength, are well established. There has been some research performed by the single fibre pull out test [13] for estimating the apparent interfacial shear strength of natural fibre composites. The fibre matrix interphase can be improved by surface treatments which alter the fibre properties (in terms of morphology, topography, wettability, adhesion) [14].

The interactions at the interface region in semi-crystalline thermoplastic composites depend on a number of factors such as matrix morphology, fibre surface condition, presence of residual stresses, and modulus of the fibre and matrix. A majority of these characteristics are affected by processing conditions including molding temperature, cooling rate, holding time/temperature and annealing conditions [15]. Accordingly, manufacturing of high-performance engineering materials from renewable resources has been pursued by researchers across the world owning to renewable raw materials are environmentally sound and do not cause health problem. The prominent advantages of natural fibres include acceptable specific strength properties, low cost, low density, high toughness, good thermal properties, and so on.

Materials and methods

Materials

The chicken feathers were bought from M/s Suguna Poultry Industry, Tamilnadu, India. To reduce the variability of feather fibre the feathers were collected from the chickens grown at the same condition. The chicken feathers are washed with hot and cold water. Sterilization was done with 95% ethanol, then rinsed with water and air-dried. To maintain the uniformity of the fibre length the tip and the base were cut and removed. From the chicken feather the barb portions were cut by using surgical blades. The barb portions can be noticed from fig. 1. The obtained chicken feather fibre length is between 25 to 32 mm, strength is 2.65 g/den, moisture regain 12%, breaking extension 1 to 6% and density of 1.12 g/cc.

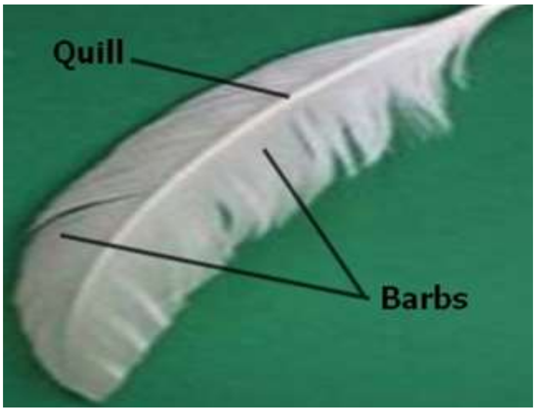

Fig. 1. Diagram of chicken feather

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The polypropylene staple fibre APOLON® was bought from M/s Zenith fibres Ltd., Baroda, India. The polypropylene fibre length is 51 mm, denier 2.5, tenacity 6 g/denier, melting temperature 163°C and density of 0.91 g/cc. In the composite board the fibre reinforcement material is chicken feather fibre and the resin is polypropylene.

Design of Experiment

Response surface methodology is an experimental modelling technique dedicated to the evaluation of the connection of a set of controlled experimental factors and observed results. It requires prior facts of the process to achieve statistical model. A detailed account of this technique has been outlined. Basically this optimization process involves three major steps, performing the statistically designed experiments, estimating the coefficients in a mathematical model, and predicting the response and checking the competence of the model. The significant variables like temperature, pressure and time were chosen as the critical variables and selected as X_1, X_2 and X_3 respectively. The low, middle, and high levels of each variable were designated as -1, 0, and +1 respectively, and given in table 1. Computation was carried out using multiple regression analysis using the least squares method.

In a system involving three significant independent variables X_1, X_2, X_3 the mathematical relationship of the reaction on these variables can be approximated by the quadratic (second degree) polynomial equation and shown in eq. (1).

$$Y = C_0 + C_1X_1 + C_2Y_2 + C_3X_3 + C_{11}X_1{}^2 + C_{22}X_2{}^2 + C_{33}X_3{}^2 + C_{12}X_1X_2 + C_{13}X_1X_3 + C_{23}X_2X_3 \quad (1)$$

Where
Y = predicted results,
C_0 = Constant,
C_1, C_2 and C_3 = linear Coefficients,
C_{12}, C_{13} and C_{23} = cross product Coefficients
C_{11}, C_{22} and C_{33} = quadratic Coefficients

The levels of variables like temperature, pressure and time are chosen based on the melting point of the resin used, final thickness (minimum of 5 mm) expected in the composite board and the effect of thermal exposure period respectively. A multiple regression analysis is done to obtain the coefficients and the equation can be used to predict the response. The degree of experiments chosen for this study was Box-Behnken, a fractional factorial design for three independent variables. It is applicable once the critical variables have been identified [31].

Table 1. Levels of variables chosen

Variables	Levels		
	-1	0	+1
Temperature, ^{0}C (X_1)	165	175	185
Pressure, bar (X_2)	5	10	15
Time, min (X_3)	3	6	9

In the model given in Equation 1, interactions higher than first order have been neglected. The design is preferred because relatively few experimental combinations of the variables are adequate to estimate potentially complex response functions [31]. A total of 15 experiments were necessary to estimate the 10 coefficients of the model using multiple linear regression analysis, the set of coefficients for its mechanical properties was calculated.

Manufacturing of composite boards

Mixing of chicken feather fibre with polypropylene (ratio 1:1) is done homogenously by manual blending. After the mixing of fibres (chicken feather fibre and polypropylene), these are fed into miniature carding machine for four times to ensure the homogenous blending and finally the web were collected of a dimension of 350 mm x 350 mm and four plies were made to produce a composite board . The collected webs are stored in atmospheric condition for 24 hrs. The technical specification of miniature carding machine is given in table 2.

Table 2. Technical specification of miniature carding machine

Particulars	Licker-in	Cylinder	Doffer
Diameter (inch)	5	10	7
Wire Points (per square inch)	4	860	403
Wire type/ angle	ICC/ 40°	ICC/ 55°	ICC\ 60°
Speed (RPM)	1000	350	10

Based on the TGA the webs were conditioned at 115°C for 24 hrs to remove any moisture present in it. Composite boards are produced from carded web by using compression

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moulding technique [16]. Fibrous webs are cut into pieces and placed on the mould. To attain uniform surface in the composite, two aluminium foils are used inside top and bottom surface of the mould. Webs are stacked to get the required weight/unit area (1000 Grams per square meter). The platens are pressed to desired specific pressure and temperature for pre-defined time to get moulded product. After completion of compression cycle, the platens are allowed to cool at atmospheric condition and then the pressure is released to take out the board. Several of such fibre webs were compression molded by varying the process parameters such as temperature, pressure and time. A sample of chicken feather fibre reinforced polypropylene composite board manufactured is shown in fig. 2.

Fig. 2. Chicken feather fibre reinforced polypropylene composite board

Tensile strength test

All tensile testing specimens were cut into dog-bone shape. The tensile tests were conducted according to ASTM 1882L using INSTRON (Model 4301) Universal Testing Machine, USA, with load cell of 1 KN, using a crosshead speed of 5 mm/min until tensile failure was detected (Fig. 3). Tests were performed until tensile failure occurred. Seven specimens were tested and at least five imitate specimens were presented as an average of tested specimens.

Scanning electron microscope analysis

The morphology and microscopy of composite samples were studied by using JSM 6510 high resolution Scanning Electron Microscope (SEM) manufactured by JEOL. Prior to the analysis, the specimens were placed on a stub and were coated with thin layer of gold using sputter coater to avoid charging under the electron beam.

Fig. 3. Instron tester

ANOVA analysis

Statistical analysis of variance (ANOVA) technique was used to check the of test results of tensile strength by comparing the pressure with Temperature and Time is carried out and accordingly F-ratios were calculated for 95% level of confidence by using MS Excel software 2007.

Results and discussion

An adjoint of a bounded linear operator T is also linear, bounded and unique. This can be shown by the result below.

The tensile strength of the composite material is obtained and compared with the predicted results as shown in Table 5. The observed results are used to get the regression equation and it is obtained after giving coded values of temperature, pressure and time as showed in eq. (2).

$$Y = 1.7 + 0.25*(X_1) + 0.50*(X_2) + 0.07*(X_3) - 0.11*(X_1^2) + 0.08*(X_2^2) - 0.01*(X_3^2) - 0.02*(X_1*X_2) - 0.12*(X_1*X_3) - 0.02*(X_2*X_3) \quad ..(2)$$

Where, '*Y*' is the predicted response. The tensile strength from each experimental point is summarized in table 3. The interactions were good enough to obtain a R^2 value of 95.97% which was obtained by the statistical software Minitab 15.

Table 3. Run order, variables, actual results and predicted results for tensile strength

Run order	Temperature (°C)	Pressure (bar)	Time (min)	Actual results (N)	Predicted results (N)
1	1	-1	0	1.9	2.2
2	0	1	-1	1.8	1.7
3	0	0	0	1.7	2.1
4	0	1	1	1.8	1.7
5	-1	0	1	1.6	1.1
6	0	0	1	1.7	1.7
7	-1	0	-1	1.1	1.7
8	1	1	0	2.0	1.8
9	1	0	-1	1.8	1.4
10	-1	-1	0	1.3	1.1
11	0	0	0	1.7	1.3
12	0	-1	-1	1.7	1.7
13	1	0	1	1.8	2.1
14	-1	1	0	1.5	0.9
15	0	-1	1	1.8	1.7

Effect of process variables on tensile strength of chicken feather fibre composite

The effects of process variables on tensile properties of the composites can be effectively analyzed by contour plot developed using Minitab 15 software. The information available from contour plot diagram regarding the interactions of process parameters on mechanical properties is very much useful to manufacture a chicken feather fibre composite board to explore its potential applications. The effect of process parameters on tensile strength of chicken feather fibre composites with respect to temperature, pressure and time obtained from experimental results are shown in fig. 4, 5 and 6.

The effect of tensile strength with respect to pressure and temperature is shown in fig. 4 by keeping central value of time as constant. From the figure it was observed that the maximum tensile strength 1.9 N was obtained, when the pressure and temperature were at maximum. It is apparent that the increase in temperature with constant pressure shows steady values in the tensile strength which ranges from 1.8 to 1.9 N. The impact of temperature is higher on the tensile strength compared to that of pressure. The polypropylene resin is softened and modified at elevated temperatures and moderate pressure which makes the ability of the resin to protect and unify the fibres, as well as transfer of stress between fibres, hence the interface between the fibre surface and resin will be bound strong.

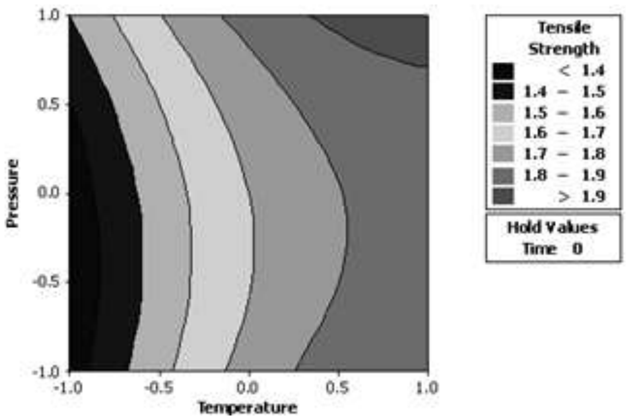

Fig. 4. Contour Plot of tensile strength versus pressure (bar) and temperature (°C)

The influence of temperature and time with respect to tensile strength by keeping the central value of pressure as constant is shown in fig. 5. It is observed that increase in time is not contributing significant difference in tensile strength. But increase in temperature plays an important role in increasing the tensile strength of the composite. When the temperature increased at the range of 0.5 (180°C) to 1.0 (185°C) the maximum tensile strength obtained was 1.8 N. Melting happens when the polymer chains fall out of their crystal structures and become a disordered liquid. Because of this good binding will be occurring between the reinforcement fibres which in turn increase the tensile strength of the composite. At lower temperature, the viscosity of polypropylene is very high and cause non-homogenous distribution of the fibres during processing.

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Consequently, this will be followed by lower tensile strength.

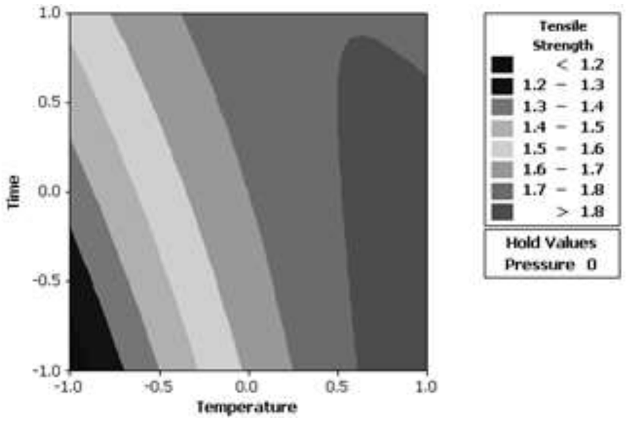

Fig. 5. Contour plot of tensile strength versus time (min) and temperature (°C)

The influence of time and pressure with respect to tensile strength by keeping the central value of temperature as constant is shown in fig. 6. It is evident that when the pressure increased the tensile strength is also increased with minimum exposure of time. This is due to the fact that the increase in pressure makes the fibre and matrix to be compressed enough to create a composite with better strength.

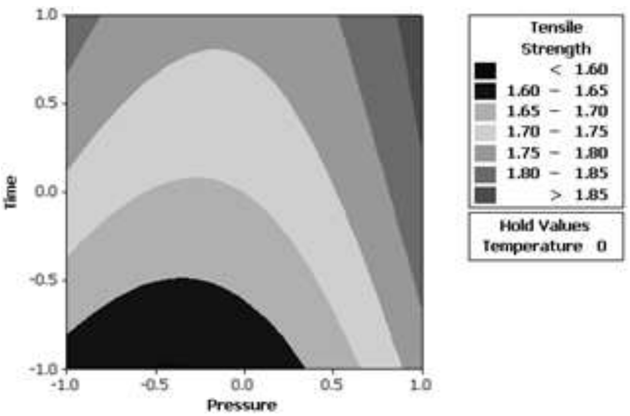

Fig. 6. Contour plot of tensile strength versus time (min) and pressure (bar)

SEM Analysis

Surface properties of chicken feather fabrics reinforced polypropylene resin based composites were investigated by SEM. Fig. 7(a) and (b) shows the SEM pictures that reveals the tensile fracture surface of composite board with lowest and highest tensile strength obtained in run order 7 and 8 respectively as indicated in the design of experiments. SEM observations indicated that based on the processing variables there is a considerable difference in the fibre matrix interaction between the composites. Fibre pull out phenomena is observed from the samples. Gaps between chicken feather fibre and matrix are found for composite board manufactured with low pressure and temperature and these samples are responsible for the low mechanical properties of the composites.

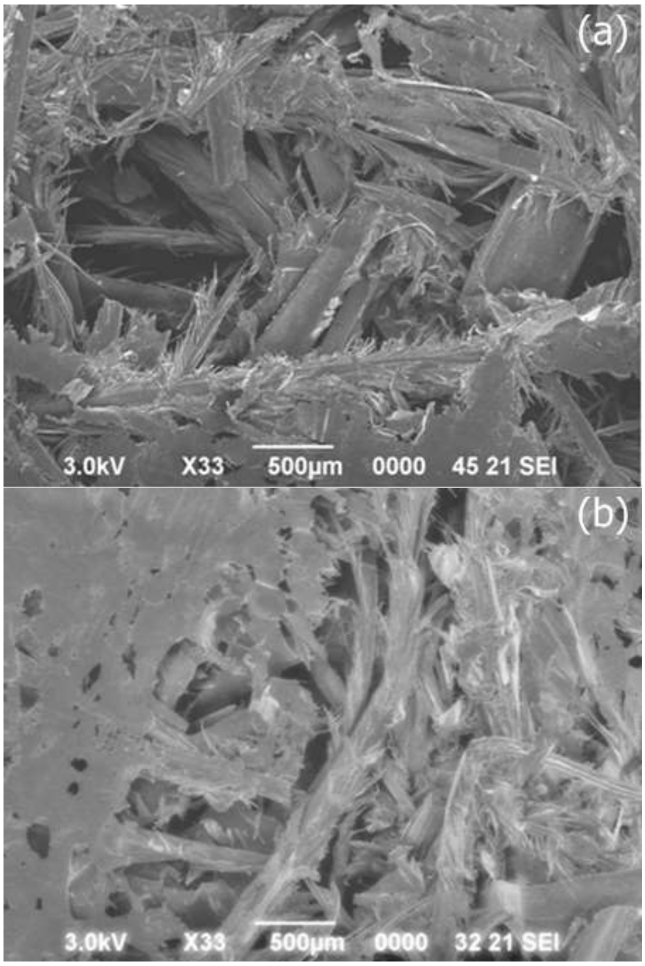

Fig. 7. SEM images of tensile fracture surface of composite boards (a) run order 7 and (b) run order 8 respectively

ANOVA

The mechanical properties of the chicken feather fibre composite of all the samples was analyzed using statistical tool of multivariable ANOVA and their values are given in table 4. From the result it is observed that there is significant difference found between the samples at 95% confidence level which shows F_{actual} and $F_{critical}$ for pressure vs. temperature as (7.882 > 6.944) and (89.762 > 6.944). For time vs. temperature as (1.161< 6.944) and (8.419 > 6.944) respectively. It is due to the change in parameters like temperature, pressure and time. It is evident from the ANOVA analysis that the temperature plays a significant role followed by pressure and insignificant influence by the time. At 99% confidence level the $F_{critical}$ value is 18 for all the parameters, hence only the temperature has significant effect on tensile strength.

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Table 4. ANOVA: Two-Factor without replication

Source of Variation	SS	df	MS	F	P-value
For Pressure vs. Temperature					
Pressure	0.037	2	0.018	7.88	0.04
Temperature	0.423	2	0.211	89.7	0.00
Error	0.009	4	0.002		
Total	0.470	8			
For Time vs. Temperature					
Time	0.053	2	0.026	1.16	0.40
Temperature	0.390	2	0.195	8.41	0.03
Error	0.092	4	0.023		
Total	0.537	8			

Response optimization

With the help of Minitab 15 software the response optimization were found and from the fig. 8 it can be noted that the increase in temperature contributing to the increase in tensile strength followed by pressure. There is no contribution made by time. To achieve the maximum tensile strength, from the available samples the optimum values would be of temperature 185°C, pressure 15 bar and time 3 min. It is evident that higher the temperature higher will be the tensile strength, but the temperature may not be increased above 185°C because as per the TGA carried out in air atmosphere, the chicken feather fibre decomposing exothermic peak starts from 186-335°C.

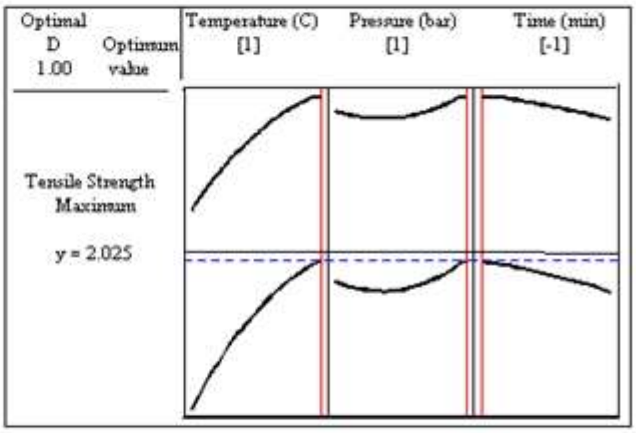

Fig 8. Response surface optimization graph

Conclusions

Chicken feather fibre reinforced polypropylene resin based composite boards were prepared by using compression moulding machine. The tensile strength of chicken fibre composite produced with varying the parameters has been analyzed and the following conclusions were arrived. The parameter temperature plays a significant role followed by pressure to obtain high tensile strength as observed because of the good interface between fibre and resin at high temperature and pressure. The maximum tensile strength 2.0 N obtained at the following process parameters; temperature-185°C, pressure-15 bar and time-3 min. With the exposure of minimum time (3 min) it is sufficient to obtain high tensile strength. The SEM picture supported that processing variables will alter the fibre-matrix interaction between the composites. Due to the micro void space in the chicken feather fibre it can be used as acoustic board in automobiles sector.

Conflicts of Interest

The authors hereby declare that they have no conflict of interest.

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