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Original article

THE INFLUENCE OF HEAT TREATMENT REGIMES ON THE MECHANICAL PROPERTIES OF UNSATURATED POLYESTER RESIN COMPOSITES REINFORCED WITH FIBERGLASS FOR AGRICULTURAL MACHINERY WORKING PARTS

I.R. Antypas

Abstract

Background. In modern agriculture, enhancing the durability and efficiency of machinery components, such as soil tiller blades, is crucial for improving productivity and sustainability. In this context, the study of advanced materials like glass fiber-reinforced unsaturated polyesters presents a relevant challenge.

Purpose. The aim of this research was to experimentally investigate the possibility of improving the properties of this composite material for the production of agricultural machinery parts.

Materials and Methods. For the study, samples were made from glass fiber-reinforced unsaturated polyester with various proportions of added components. The samples were divided into two groups: one group underwent thermal treatment, while the other remained untreated. Mechanical property testing was conducted using standard tensile tests to determine the values of tensile strength. Observations were also made regarding changes in mechanical properties under prolonged heat exposure.

Results. The results showed that samples with optimized proportions of added components, without direct thermal treatment, exhibited lower tensile strength values compared to samples that underwent thermal treatment. However, with prolonged application of heat over a relatively long period, the strength values began to decrease significantly. This indicates that extended heating leads to increased brittleness of the polyester composition and enhances reactions occurring within the mixture, negatively affecting the strength properties of the material under investigation.

Conclusion. The obtained data indicate a complex relationship between thermal treatment and the strength characteristics of the material. While thermal treatment may initially improve properties, prolonged heat exposure can lead to structural degradation and reduced strength. These results highlight the importance of optimizing technological processes in the production of soil tiller bladeto achieve a balance between enhancing mechanical properties and preventing undesirable changes associated with thermal treatment. Tensile test results showed that proportions approved for the production of glass fiber-reinforced unsaturated polyester soil tiller blade without direct thermal treatment lead to lower tensile strength values compared to thermally treated samples. This suggests incomplete curing of the mixture, resulting in a reduction of the studied mechanical properties. Furthermore, prolonged heat exposure for a relatively long duration (up to 72 hours) caused a significant decrease in tensile strength values. This indicates that prolonged heating enhances the reactions occurring within the mixture, leading to increased brittleness of the polyester composition and adversely affecting its strength characteristics. The study demonstrated that the correct choice of component proportions and thermal treatment regimes is critical for achieving optimal mechanical properties of glass fiber-reinforced unsaturated polyesters. These results could serve as a foundation for further research and development in materials science aimed at creating more efficient and durable materials for use in agricultural machinery.

Keywords: fiberglass reinforced plastic; polyester; soil tiller blade; Thermal treatment; composite material

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Научная статья

ВЛИЯНИЕ РЕЖИМОВ ТЕРМИЧЕСКОЙ ОБРАБОТКИ НА МЕХАНИЧЕСКИЕ СВОЙСТВА ИЗДЕЛИЙ ИЗ НЕНАСЫЩЕННОГО ПОЛИЭФИРНОГО СВЯЗУЮЩЕГО, АРМИРОВАННОГО СТЕКЛОВОЛОКНОМ, ДЛЯ РАБОЧИХ ОРГАНОВ СЕЛЬСКОХОЗЯЙСТВЕННЫХ МАШИН

И.Р. Антибас

Аннотация

Обоснование. В современном сельском хозяйстве повышение долговечности и эффективности компонентов машин, таких как лопасти почвообрабатывающих фрез, имеет решающее значение для роста производительности и устойчивого развития. В этом контексте исследование перспективных материалов, например, ненасыщенных полиэфиров, армированных стекловолокном, представляет собой актуальную задачу.

Цель. Целью данного исследования было экспериментальное изучение возможности улучшения свойств этого композиционного материала для производства деталей сельскохозяйственных машин.

Материалы и методы. Для исследования были изготовлены образцы из ненасыщенного полиэфира, армированного стекловолокном, с различным соотношением компонентов. Образцы разделили на две группы: одну группу подвергли термической обработке, а другую оставили без обработки. Механические свойства испытывали с помощью стандартных испытаний на растяжение для определения прочности. Также проводили наблюдения за изменением механических свойств при длительном тепловом воздействии.

Результаты. Результаты показали, что образцы с оптимизированным составом, но без термообработки, демонстрировали более низкую прочность при растяжении по сравнению с обработанными образцами. Однако при длительном тепловом воздействии значения прочности начали существенно снижаться. Это указывает на то, что продолжительный нагрев приводит к повышению хрупкости полиэфирной композиции и интенсификации протекающих в ней реакций, что негативно сказывается на прочностных свойствах исследуемого материала.

Заключение. Полученные данные свидетельствуют о сложной взаимосвязи между термообработкой и прочностными характеристиками материала. В то время как кратковременная термическая обработка может улучшать свойства, длительное тепловое воздействие вызывает структурную деградацию и снижение прочности. Эти результаты подчеркивают важность оптимизации технологических процессов при производстве лопастей для достижения баланса между улучшением механических свойств и предотвращением нежелательных изменений, связанных с нагревом. Результаты испытаний на растяжение показали, что выбранный состав для производства лопастей почв фрезы без термообработки приводит к более низкой прочности по сравнению с термообработанными образцами. Это позволяет предположить неполное отверждение смеси, что и вызывает снижение механических свойств. Кроме того, длительное тепловое воздействие (до 72 часов) вызывало значительное падение прочности. Это свидетельствует о том, что продолжительный нагрев усиливает реакции в материале, приводя к повышению хрупкости полиэфирной композиции и ухудшению её прочностных характеристик.

Ключевые слова: стеклопластик; полиэфирная смола; изделия; термическая обработка; композиционный материал

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Introduction

Fiberglass-reinforced plastics (FRP) have found extensive applications in various industries due to their excellent strength-to-weight ratio, corrosion resistance, and ease of processing [1–5]. The mechanical performance in the manufacture of composite soil tiller blade depends on the properties of the polymer matrix, the quality and configuration of the fiber reinforcement, and the curing regime applied during fabrication.

The polymerization and curing of unsaturated polyester (UPR) resins can be effectively controlled through adjustments in the initiator and accelerator ratios, as well as by applying post-curing heat treatment [6; 7]. Previous studies [8; 9] have shown that both material composition and processing temperature have a pronounced influence on tensile strength, stiffness, and brittleness of polyester composites.

Recent investigations [10] confirmed that the incorporation of mineral fillers such as sodium aluminosilicate and talc significantly enhances the stiffness and tensile strength of UPR-based composites. However, comprehensive experimental research on the combined effects of heat-treatment duration and temperature on the mechanical behavior of fiberglass-reinforced UPR remains limited-especially for large structural components such as soil tiller blade.

In recent years, several studies have examined related aspects of post-curing, thermal aging, and heat treatment of polyester and other thermosetting resin composites. For instance, it was shown that bending strength and viscoelastic performance of polyester materials increase notably when post-cured at moderate temperatures (40–60 °C) over controlled exposure durations [11].

Moreover, subsequent investigations [12] demonstrated that moderate post-curing temperatures around 60 °C can improve ductility and tensile strength, whereas excessive thermal exposure tends to reduce elongation and induce brittleness.

Similarly, in [13], the authors reported that prolonged exposure of UPR–glass composites to elevated temperatures (60–150 °C) may initially enhance certain mechanical parameters, but higher temperatures can compromise dimensional stability.

Furthermore, [14] explored the combined effect of chopped glass fibers and TiO_2 nanoparticles, revealing that both heat resistance and tensile strength can be substantially improved through the synergistic action of optimized reinforcement and appropriate curing regimes.

These studies indicate that the temperature, duration, and additives in UPR composites have important and interdependent effects on mechanical properties. However, there remains a gap in identifying the precise curing regimes (initiator %, heat-treatment temperature, time) that optimize tensile strength without leading to brittleness or structural defects in full materials. The **aim** of the work was to determine the optimal content of the MEKP initiator and the subsequent heat treatment regime (temperature, time) to maximize the tensile strength of a fiberglass-reinforced unsaturated polyester-based composite.

Materials and methods

In the experimental study, samples based on unsaturated polyester resin reinforced with (4-6-8) consecutive layers of random glass fibers were prepared using the following materials:

1. Matrix: unsaturated polyester resin, as it is one of the most important thermosetting resins used in fiber-reinforced composite materials (Fig. 1), the main properties of which are presented in Table 1.

Table 1.

Main properties of unsaturated polyester resin

Main properties	Значение	Размерность
Pink viscous liquid		
Viscosity at 30 °C	450-650	Cps
Gelation time at 30 °C with addition of 1.5% MEKP	15-20	минут
Flash point	34	°C
Срок хранения	4	месяцев

Fig. 1. Unsaturated polyester

2. Reinforcement: Random-oriented glass fibers (11.2 g/m²), providing strength, chemical stability, and low density. This type of fiber has found wide application in various technical fields (Fig. 2).

Fig. 2. Glass fiber used

3. Reaction initiator: Methyl ethyl ketone peroxide (MEKP) was used to convert unsaturated polyester, helping to transform it into a solid state. The curing time of the process is controlled by the percentage content of this material. In an experimental study to investigate the influence of percentage content on stress, three different percentages of this material were used (1%, 1.5%, and 2%).

4. Reaction accelerator: A solution of cobalt naphthenate was used to accelerate the process. Accelerators increase the rate of peroxide penetration into free radicals, aiding in controlling the polymerization rate of polyester resins.

5. Mold: An aluminum mold measuring 20 x 20 x 0.5 cm was used for sample fabrication, facilitating the extraction of samples after curing.

2.1 Sample preparation method

The test samples were prepared using a hand lay-up method, which is traditional in composite soil tiller blade manufacturing and is known for its low cost.

In the first step, the mold is prepared and cleaned, removing any dust and dirt [9]. Then, several layers of wax are applied to the inner surface of the mold to prevent materials from sticking to the walls during curing. Next, a layer of unsaturated polyester is manually applied to the inner surface of the mold using a paintbrush. The fibers are trimmed to fully cover the sample. Catalyzed resin is then applied using the brush. This process is repeated using a roller and adding resin as needed until all white areas on the fibrous material disappear and no air bubbles remain. A mohair roller is ideal for achieving uniform resin distribution and removing any remaining air bubbles, while a corrugated plastic or aluminum roller helps effectively eliminate bubbles.

Samples with varying numbers of layers of random glass fiber (4-6-8) were manufactured using the hand lay-up method with different percentages of the initial MEKP material (1%, 1.5%, and 2%). They were then subjected to thermal treatment according to the following system: the samples were placed in an oven at a temperature of 60 °C for different time intervals: 2, 24, 48, and 72 hours.

2.2 Measurement methodology

Tensile test samples with dimensions of 2 x 24 cm were cut from thermally treated plates. The rectangular shape of the samples was chosen due to the lack of a specific geometric form for conducting tensile tests. The rectangular shape of the samples is widely used when working with non-polyester compounds, as the relative deformation of such compounds is minimal. The length of the working part of the sample is not significant, as this allows for the use of samples of varying lengths depending on the testing machine used. Tensile testing of the samples was conducted in accordance with ISO 6259 on a universal testing machine at a speed of 5 mm/min (Fig. 3).

Fig. 3. Tensile testing machine and test samples

Results and discussion

Fig. 4 shows the values of tensile stresses at break in terms of both the number of reinforcing layers and the percentage content of peroxide primer (MEKP). As can be seen, the strength values at break increase with an increase in the number of reinforcing layers. It can also be observed how the added percentage of peroxide affects the results, with the best values obtained by samples containing 1% peroxide. This result is unexpected due to its inconsistency with the recommendations accompanying the original material, which suggest that the optimal peroxide content should be 1.5%.

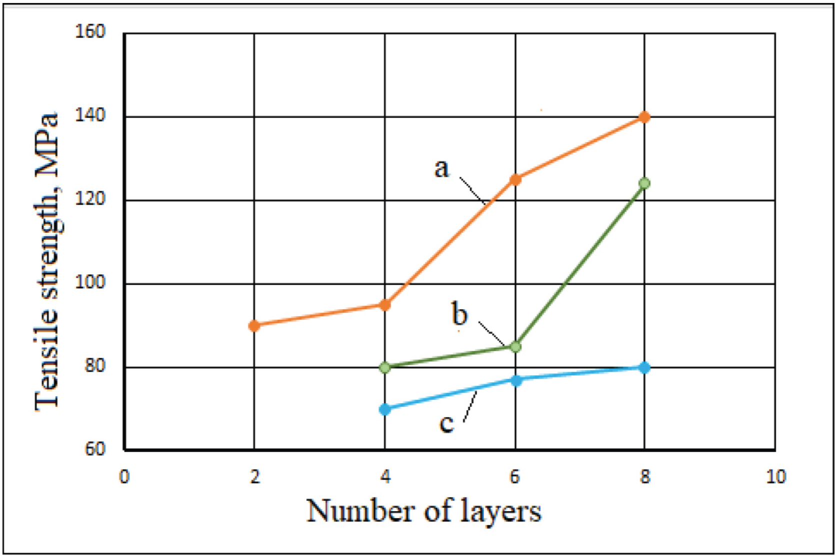

Fig. 4. Tensile stress at break curve variations depending on the number of random glass fiber layers in UPR matrix and catalyst content: a) -1%, b) - 1.5%, c) - 2%

It should be noted that the time period between sample preparation and testing varied, as samples containing 1% peroxide were aged for a longer period (about 4 months) compared to samples containing 1.5% and 2% (approximately 1 month).

This allowed the first samples a better chance of complete curing relatively, which explains why the test results of samples with 1% peroxide content were better than those with 1.5% content. On the other hand, the test results of samples with 2% peroxide content showed a clear and significant decrease in tensile stress values at break. The reason for this is that an excess of peroxide contributes to the formation of shape defects, such as microcracks, which act as stress concentrators in the sample structure, leading to a decrease in tensile stress values at break.

In order to eliminate the influence of time discrepancy on test results, the experiment was repeated in accordance with the manufacturer's recommendations at a 1.5% peroxide content with subsequent heat treatment immediately after production.

Accelerating the polymerization of unsaturated polyester resin mixtures is possible regardless of the proportions of the materials involved by preparing the final product in a thermal environment, as is the case when thermosetting paint materials are used to speed up the curing of car paint layers, a process that is carried out at a temperature of around 60°C. Therefore, this process can be accelerated using the following heat treatment methodology:

1. The heat treatment temperature is set at 60°C, recommended by many studies [4].
2. Heat treatment durations in hours: 2, 24, 48, and 72.

The tensile strength tests conducted on the samples clearly demonstrated the effectiveness of the chosen heat treatment method based on the property under study, and the results presented in Fig. 5 prove its enhancement.

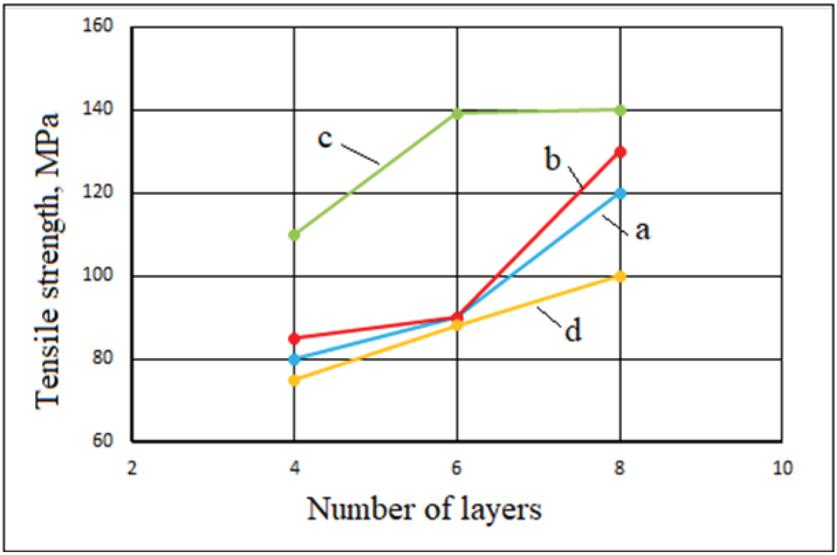

Fig. 5. Change in tensile strength at break of samples made of unsaturated polyester resin reinforced with fiberglass, with a 1.5% initiator content after: a) - 2 hours of heat treatment, b) - after 24 hours of heat treatment, c) - after 48 hours of heat treatment, d) - after 72 hours of heat treatment

In addition, the results of heat treatment showed a significant improvement in tensile strength at break, with the best results obtained after 48 hours of treatment. This indicates incomplete curing of the material at a 1.5% peroxide content and the need for further research to achieve complete curing.

The experimental study demonstrated a clear improvement that can be achieved by heat treating the samples at a temperature of 60°C for 48 hours.

The reason for this is that such a temperature regime promotes the activation of free radical formation in the mixture, as the cold curing process requires more time to complete, and mechanical processing is needed to accelerate it.

However, it cannot be certain that the chosen heat treatment regime ensures complete curing of the product and that the improvement in strength properties obtained from the treatment enhances the structural properties of the unsaturated polyester mixture and makes it more resistant to tensile stress. Finding the most suitable heat treatment regime remains an open field for scientific research, as researchers always strive to find a processing system that provides the best strength performance according to the composition of the mixture used.

Conclusion

1. The curing behavior of unsaturated polyester depends strongly on the initiator and accelerator concentrations, as well as on the thermal regime applied.
2. An initiator content of 1.5 % MEKP combined with post-curing at 60 °C for 48 h yields the highest tensile strength, indicating near-complete polymerization.
3. Excess initiator (2 %) or prolonged heating (72 h) results in microstructural defects and brittleness, reducing mechanical strength.
4. Controlled heat treatment enhances mechanical performance, but over-exposure leads to thermal degradation.
5. Optimizing the curing process is essential for improving the durability and reliability of soil tiller blade made from fiberglass-reinforced unsaturated polyester composites.

Recommendations

* Conduct microstructural (SEM) and DSC analyses to monitor crosslink density and degradation onset.

* Evaluate fatigue and environmental aging to simulate real operating conditions of soil tiller blade s.

* Develop a kinetic model describing the relationship between temperature, initiator content, and mechanical strength.

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