Lecture Notes in Mechanical Engineering

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Advances in Design, Simulation and Manufacturing II

Proceedings of the 2nd International Conference on Design, Simulation, Manufacturing: The Innovation Exchange, DSMIE-2019, June 11–14, 2019, Lutsk, Ukraine

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Preface

This volume of Lecture Notes in Mechanical Engineering contains selected papers presented at the 2nd International Conference on Design, Simulation, Manufacturing: The Innovation Exchange (DSMIE-2019), held in Lutsk, Ukraine on June 11–14, 2019. The conference was organized by the Sumy State University, Lutsk National Technical University, and International Association for Technological Development and Innovations, in partnership with Technical University of Kosice (Slovak Republic), Kielce University of Technology (Poland), University of West Bohemia (Czech Republic), Poznan University of Technology (Poland), and Association for Promoting Innovative Technologies—Innovative FET (Croatia).

DSMIE-2019 is the international forum for fundamental and applied research and industrial applications in engineering. The conference focuses on a broad range of research challenges in the fields of Manufacturing, Materials, Mechanical, and Chemical Engineering, addressing current and future trends in design approaches, simulation techniques, computer-aided systems, software development, ICT tools, and Industry 4.0 strategy implementation for engineering tasks solving. DSMIE-2019 brings together researchers from academic institutions, leading industrial companies, and government laboratories located around the world for promoting and popularization of the scientific fundamentals of manufacturing.

The book was organized in four parts, according to the main conference topics. Each part is devoted to research in design, simulation, and manufacturing in the areas of (1) Manufacturing Engineering, (2) Materials Engineering, (3) Mechanical Engineering, and (4) Chemical Engineering.

DSMIE-2019 received 190 contributions from 26 countries around the world. After a thorough peer-review process, the Program Committee accepted 92 papers, written by authors from 22 countries. Thank you very much to the authors for their contribution. These papers are published in the present book, achieving an acceptance rate of about 48%. Extended versions of selected best papers will be published in scientific journals: Management and Production Engineering Review (published by De Gruyter and indexed by ISI/ESCI, Scopus), Archives of

Mechanical Technology and Materials (Poland), and Journal of Engineering Sciences (Ukraine).

We would like to take this opportunity to thank members of Program Committee and invited external reviewers for their efforts and expertise in contribution to reviewing, without which it would be impossible to maintain the high standards of peer-reviewed papers. 93 Program Committee members and 31 invited external reviewers devoted their time and energy for peer reviewing manuscripts. Our reviewers come from all over the world and represent 29 countries and affiliate with 63 institutions.

Thank you very much to keynote speakers: Jose Machado (Portugal), Justyna Trojanowska (Poland), Michal Balog (Slovak Republic), Dragan Perakovic (Croatia), Grigore Marian Pop (Romania), and Volodymyr Zavialov (Ukraine) for sharing their knowledge and experience.

We appreciate the partnership with Springer, Unicheck, EasyChair, and our sponsors for their essential support during the preparation of DSMIE-2019.

Thank you very much to DSMIE-2019 Team. Their involvement and hard work were crucial to the success of the DSMIE-2019 conference.

DSMIE-2019's motto is "Together we can do more for science, technology, engineering, and education".

June 2019

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Contents

Manufacturing Engineering

Materials Engineering

A New Technology for Producing the Polystyrene Foam Molds Including Implants at Foundry Industry

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Abstract. Here the description of the possibility of processing technogenic waste polystyrene in binder materials for foundry is provided. The possibility of dissolving polystyrene foam in acetone. Regardless of the amount of acetone that was analyzed, polystyrene absorbs it in a 1:1 ratio, with the formation of a swollen precipitate. The obtained data of the study "polystyrene–acetone" have been successfully used as the basic elements of technology for cellular polystyrene models with implants. Here the prime factor imposing is the kinetics of polystyrene foam in acetone swelling and the swollen foamy polystyrene precipitate composition. The precipitate can be used as a binder for molding compounds. The kinetics of swelling of polystyrene foam and beaded polystyrene in acetone was studied. The data obtained in the study of the system "polystyrene foam–acetone" was used in the manufacture of polystyrene models with implants. The technology for producing polystyrene foam models with implants includes the need to use a special binder for fixing implanted granules on the surface of implanted granules. The research results allowed to propose a new technology for producing foam polystyrene models with implants without using a special binder.

Keywords: Foam polystyrene model · Foundry · New bonding materials · Acetone · Binder · Polymer

1 Introduction

Currently in the worldwide industrial practices technical and consumer packing material and food products containers' material used is the foam polystyrene. The polystyrene is not subject for recycling, as it does not react with water, being also a non-biodegradable material. Also, it can not be burnt like scrap, wood etc., due to the

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fact that during the polystyrene destruction process, essential volume of very harmful (poisonous) gases is evolving. Therefore, the large amounts of used polystyrene accumulated in the environment, creating a significant environmental problem.

Problem statement. The purpose of this research is to create techniques for polystyrene recycling, thus to develop new bonding materials that can be used in the foundry industry.

This will serve to both improving the existing and development of new highly efficient casting processes and to significant improvement of the foundries' ecological safety index.

Thus, an important task of technogenic waste processing will be solved providing a high-quality binder for foundry industry.

Research purpose. The purpose of this research is to create techniques for polystyrene recycling and thus to develop new bonding materials that can be used in the foundry industry.

2 Literature Review

Many foreign companies are conducting intensive work on finding new model materials based on polyolefin resin, polypropylene, cyclic hydrocarbons, polymethyl methacrylate and other polymers [1–10]. However, the analysis of new materials shows that in some cases it is impossible to obtain complex thin-walled models that are not inferior in quality polystyrene foam, and in other cases they are 5–6 times more expensive. So, in the coming decade, the main material for gasified models will remain polystyrene foam. Additional studies are needed to uncover the mechanisms and phenomena of the interaction of the products of thermal decomposition of gasified models with liquid and solid metals.

Foreign companies are very responsible for the production of directly gasified models, since the quality of the models largely determines the quality of the castings [2, 3]. For the manufacture of high-quality models, special polystyrene foam with a density of the starting material (640–950) kg/m^3 and an isopentane content of at least 4.5% (mass) is used. Subfoaming of the output polystyrene granules is carried out in a vapor-air medium at atmospheric pressure, vacuum or overpressure, while reaching the final density (20–30) kg/m^3. Production of models produced in autoclaves ("autoclave method") or on specialized machines (method of "thermal shock").

Molds, as a rule, are made of aluminum alloys that can withstand up to 1 million removals [4, 5]. FiatTeksid has mastered the production of molds with porous walls of a copper-nickel alloy by electroforming using plastic models, which made it possible to abandon ventilation and dramatically shorten the mold manufacturing cycle [6]. Gasified models in domestic practice are manufactured at foundries, although foreign firms producing castings using gasified models receive models for cooperation. According to [7], up to 75% of foundries produce models from specialized firms.

Inside the fluid between the molecules there are intermolecular interaction forces. They cause the attraction of molecules to each other. In order for the process of dissolution to take place, the forces of interaction between the solvent molecules and the dissolved substance must be greater than or equal to the forces of mutual attraction of the solvent molecules and the dissolved substance.

Basically, dissolution occurs as a result of diffusion, that is, the free penetration of molecules of one substance into another, while the viscosity of the mixing substances becomes of primary importance.

The reasons for the mutual solubility of substances is one of the most difficult issues in physical chemistry [8].

The ability of polymers to dissolve or swell is due to many factors: the chemical nature of the polymer and solvent, the molecular weight of the polymer, the flexibility of the polymer chain, the packing density of macromolecules, the phase state of the polymer, the heterogeneity of the chemical composition of the chain, the presence and frequency of the spatial network, temperature.

Substances that are similar in chemical structure mutually dissolve, and substances that differ in chemical structure, that is, "like dissolves in like", do not dissolve. As a sign of "similarity", the affinity of the energy of intermolecular interaction was taken. The nature of the interaction of polymers with solvents also depends on the shape and size of polymer macromolecules [9, 10].

The mechanism of dissolution of polymers consists in separation of chains from each other and their diffusion into the solvent phase. This contributes to the flexibility of the chain. The flexibility of the chain can move in parts; its links are able to exchange places with solvent molecules.

Polystyrene is a non-polar polymer and it is soluble in many non-polar solvents [11]. In amorphous polymers, chains are flexible, so they, and in particular polystyrene, dissolve in any non-polar liquid almost unlimitedly.

The solubility of polymers is greatly influenced by the packing density of macromolecules. At the same time, very flexible and very rigid chains can be packed tightly. And this can affect solubility in different ways. The good solubility of polystyrene is associated with different packaging of its macromolecules. A large influence on the solubility has a phase state of the polymer. Thus, the presence of a crystal lattice requires a significant expenditure of energy for its destruction. Therefore, active amorphous polystyrene has sufficiently good properties for successful dissolution in non-polar solvents.

The solvent is usually called the component of the solution, the concentration of which is significantly higher than the concentration of other components. In a saturated solution, the concentration of the dissolved substance is equal to the maximum possible under conditions of thermodynamic equilibrium with this substance, in a saturated solution the concentration exceeds the maximum possible value under these conditions. Such solutions are unstable, of which spontaneous release of an excess of the satiated component is possible.

Solubility refers to the thermodynamic properties of substances, since it reduces the mutual attraction force of molecules.

Therefore, the choice of solvent should be based on the thermodynamic characteristics of both the solubility of the substance and the solvent itself.

If two substances have approximately the same forces of intermolecular interaction, they are mutually mixed.

Although solvents perform a technological function, however, the performance of a material with their participation largely depends on the properties of the solvent used.

The reference sources contain quite discordant data on the polystyrene solubility in acetone: they treat it as soluble, partially soluble and even insoluble substance. And the acetone being one of solvents in extensive use at foundries, it is important to clarify the actual situation in this matter, as well as the distinction, evidently existing when ordinary polystyrene compared to polystyrene foam [12].

Even the first experiments demonstrated that the behavior of polystyrene entering in contact with acetone is very active. When Styrofoam immersed into acetone the liquid is intensively “boiling” due to the release of gas contained at the polystyrene cells. Simultaneously, the “dissolution”, or rather absorption of acetone by polystyrene takes place forming a swollen precipitate [13]. And as the polystyrene cell walls are very thin, the process is quite intense.

In a relatively short period of time the boiling ceases and over the swollen precipitate formed is a transparent layer of acetone, which was not absorbed by that first lot of polystyrene. When a new portion of polystyrene immersed in this composition “swollen polystyrene precipitate-acetone”, the liquid boiling process resumes anew, so the precipitated matter amount (volume) increases and the height of acetone transparent layer decreases accordingly. The process runs so fast that almost none delay is required for loading each new portion of Styrofoam into the sealed container. Finally, there comes a moment when we observe the absence of any transparent acetone layer over the swollen precipitate [14]. Studies effected have shown that the “polystyrene:acetone” ratio in the resulting precipitated substance approaches to 1:1. So, the polystyrene does actively absorb such quantity of acetone, which mass is equal to the polystyrene’s own mass. When a fewer acetone amount enters into contact with polystyrene, it will be completely absorbed by polystyrene. When the acetone presence index exceeds the ratio of 1:1, its separation is revealed as a clear layer over the swollen precipitate takes place. Thus, we can conclude that the polystyrene regardless of excessive acetone mass, absorbs the amount necessary to form the swollen precipitation in which the “polystyrene: acetone” ratio by masses is equal to 1:1.

The swollen polystyrene-acetone precipitate composition represents a slow-flowing mass of light color, very viscous and sticky that due to the high volatility of acetone in the air is quickly solidified [15]. Therefore, it is difficultly portioned thus we should recognize such its state as not fit to be manufactured for the use in molding compositions. Attempts to average such substance’s composition and to thin the precipitate with excessive acetone that was not absorbed gave no positive results, since the viscous precipitates ticks onto the mixer’s activator, not being distributed uniformly over the “swollen precipitate-acetone” composition volume.

Despite these difficulties, researching the polystyrene swollen precipitate in acetone as a binder to be used at molding mixtures is of considerable interest, considering a very high strength and hardness of such precipitate after removal of acetone, as a result of high volatility in the air [16]. This swollen polystyrene precipitate of foamed polystyrene after acetone evaporation becomes a stone-hard body. This result confirms the fact that the solvent is not a secondary component and has an essential impact onto the final product properties formation.

3 Research Methodology

As noted earlier, the process of polymers dissolving in a specified order passes through the swelling stage [17]. For polymers with limited swelling index (foam polystyrene-acetone), this is the final stage, i.e. it is not accompanied by further polymer dissolving and formation throughout the volume of its true solution.

Usually the process of high-molecular substances swelling is a time-dependent and has a certain speed. Therefore, measuring the polymer swelling degree at regular intervals we can study the kinetics of polymer swelling.

If m_o—mass of the polymer prior to swelling and m—its mass after swelling, we get the relation:

$$\frac{(m - m_0)}{m_0} = \alpha. \tag{1}$$

The value of α is called the degree of swelling, which is numerically equal to the mass of liquid absorbed by 1 g of polymer [18].

Time to reach the maximum swelling degree varies for different polymers. To properly assess the polymer swelling capacity index, we should use the maximum index value "α". The maximum swelling can be observed in polymers that are limited-swelling in some given liquid [19]. The low-swelling polymers begin to dissolve over time, at that not an increase, but a decrease in mass of the sample is observed.

4 Results

Figure 1 and Table 1 represent data on the kinetics of Styrofoam and beaded polystyrene swelling in acetone [20]. It is seen that the acetone absorption by polystyrene foam and polystyrene bead is rapid and almost ends for 1 h [21]. At that the foamy polystyrene absorbs much more acetone than beaded polystyrene. Thus, if the degree of foamy polystyrene swelling during first 5 h is 1.15, the polystyrene bead swelling index is only 0.7.

The further beaded polystyrene maturation in contact with acetone for 5 days results in a slightly increased swelling, but this increase is not significant [22].

As for polystyrene foam, the maturation exceeding 24 h results in a marked decrease of the swelling degree, reaching the "1" index cipher, that is explained with some compaction and sequentially increases the experiment accuracy. Simultaneously, the data obtained suggest that the swollen polystyrene foam precipitate's content with acetone is equal to ratio of "polystyrene:acetone" as 1:1.

The obtained data of the study "polystyrene-acetone" have been successfully used as the basic elements of technology for cellular polystyrene models with implants. Here the prime factor imposing is the kinetics of polystyrene foam in acetone swelling and the swollen foamy polystyrene precipitate composition.

Such a new technology for foam polystyrene models with implants (Fig. 2) eliminates the need to apply special binder for fixing the implants at the foamed pellets surface [23]. Instead such a binder a strictly administered dosage amount of acetone is

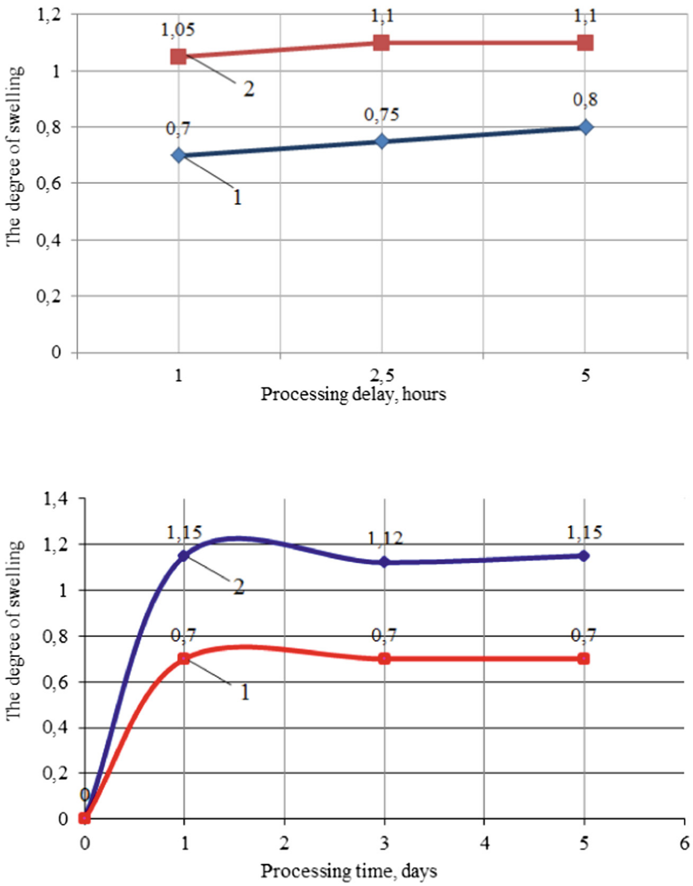

Fig. 1. Kinetics of primary styrofoam swelling at acetone: 1—primary beaded polystyrene; 2—foamy polystyrene.

Table 1. Kinetics of Styrofoam and beaded polystyrene swelling in acetone.[a]

Name of material	Hours			Days		
	1	3	5	1	3	5
Styrofoam	1.15	1.12	1.15	1.02	1.00	0.99
Beaded polystyrene	0.7	0.7	0.7	0.73	0.76	0.78

[a] Swelling do characterize the degree of swelling α, determined by the formula

entered into mixing device, further evenly distributing the acetone over the surface of foamed polystyrene granules actively absorbing it. Thus the surface of these pellets forms a thin layer of adhesive mass which is binding for implants [24].

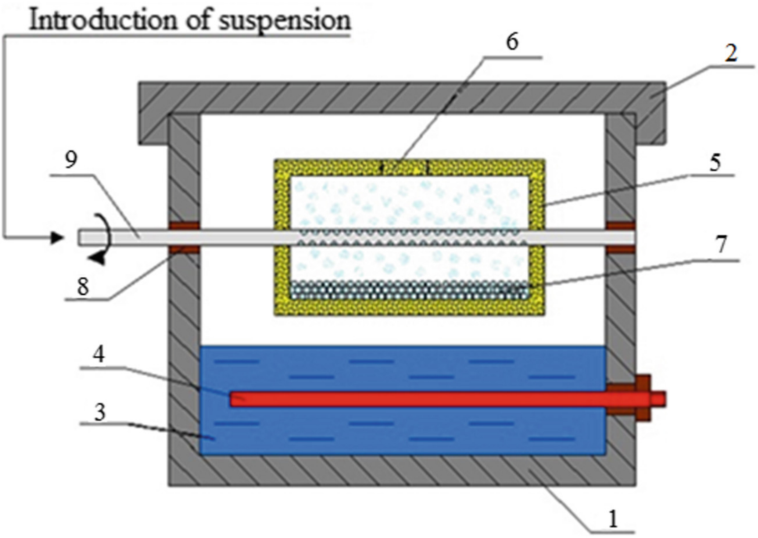

Fig. 2. Technological process of concurrent pellets' foaming and additives introducing: 1—foamers; 2—cover; 3—heat carrier; 4—heather; 5—drum; 6—hatch for introducing the primary polystyrene; 7—polystyrene pellets; 8—bearings; 9—hollow axle.

And since according to the swelling kinetics data the process is very fast and the "polystyrene:acetone" ratio is 1:1, thus created are all necessary conditions for the qualitative binding of entered components (alloying, modifying) with the surface of foamed polystyrene granules [25].

5 Conclusions

In the study of the "polystyrene-acetone" system it is found that polystyrene is insoluble in acetone, but it is characterized by a limited swelling at a polystyrene to acetone ratio of 1:1 and a short-cycle absorption (15–30 min). Therefore it is possible to develop a new technology for styrofoam-based molds containing implants, that will eliminate the need for a special binder fixing implants on the surface of foamed polystyrene granules.

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