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Original Research

MECHANICAL MIXING AND DEAERATION STATION FOR ADHESIVE COMPOSITIONS

STANOWISKO DO MECHANICZNEGO MIESZANIA I ODPOWIETRZANIA KOMPOZYCJI KLEJOWYCH

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Abstract

This paper presents the design of a specialised mixing and deaeration station for adhesive compositions. The aim of the work was to present a device for simultaneous mixing and gas bubble removal, as well as to verify the correctness of the practical application of the station by conducting experimental tests. In the experimental research, the subject of the study was an adhesive composition of the Epidian 5 epoxy resin with the PAC curing agent, which was prepared using four mixing methods carried out with the use of the station for simultaneous mixing and deaeration. The first mixing variant (V1) consisted of mixing the adhesive composition with a paddle mixer at 1170 rpm for 3 minutes, while in the second variant (V2) mixing was carried out with a dispersing disc mixer at 1170 rpm for 3 minutes. The third variant (V3) of mixing was carried out as variant 2, except that the adhesive composition was subjected to deaeration during mixing, while variant 4 (V4) additionally used deaeration of the composition after the mixing process for 2 minutes. The tested adhesive composition was physically modified by adding particles of calcium carbonate CaCO3 to verify the correct mixing of the composition components. The prepared samples were subjected to tensile and compressive strength tests. The structure of the prepared samples was also analysed using scanning electron microscopy (SEM). The tests carried out showed that the stand for simultaneous mixing and deaeration of adhesive compositions meets the expectations set for it. Mixing variant 4, in which mixing was realised using a dispersing disc mixer, proved to be the most favourable mixing method. Mixing was carried out at a speed of 1170 rpm for 3 minutes. In addition, during the mixing process, a deaeration process of the mixed composition was carried out, as well as deaeration was realised after the mixing process in a time of 2 minutes. Changing the mixing parameters contributed to an increase in both the tensile strength and compressive strength of the tested compositions. SEM analysis of the observed samples showed that changing the mixing parameters reduced the amount of air bubbles in the adhesive structure and, in the case of modified compositions, resulted in a better distribution of the filler in the structure of the mixed compositions.

Keywords: mixing, adhesive process, adhesive composition, SEM

Streszczenie

W niniejszej pracy przedstawiono projekt specjalizowanego stanowiska do mieszania i odpowietrzania kompozycji klejowych. Celem pracy była prezentacja urządzenia do jednoczesnego mieszania i usuwania pęcherzy gazowych, a także sprawdzenie prawidłowości praktycznego zastosowania stanowiska przez przeprowadzenie badań doświadczalnych. W badaniach doświadczalnych przedmiotem badań była kompozycja klejowa żywicy epoksydowej Epidian 5 z utwardzaczem PAC, którą przygotowano z zastosowaniem 4 sposobów mieszania realizowanych z użyciem stanowiska do jednoczesnego mieszania i odpowietrzania. Pierwszy wariant mieszania (V1) polegał na mieszaniu kompozycji klejowej mieszadłem łopatkowym z prędkością 1170 obr/min w czasie 3 minut, w drugim wariancie (V2) mieszanie realizowano z zastosowaniem mieszadła tarczowego dyspergującego z prędkością 1170 obr/min w czasie 3 minut. Trzeci wariant (V3) mieszania był realizowany tak jak wariant 2, z tym że kompozycję klejową poddano odpowietrzaniu w trakcie mieszania, natomiast w wariancie 4 (V4) zastosowano dodatkowo odpowietrzanie kompozycji po procesie mieszania w czasie 2 minut. Badaną

kompozycję klejową poddano fizycznej modyfikacji poprzez dodanie cząsteczek węglanu wapnia $CaCO_3$ celem weryfikacji poprawności zmieszania składników kompozycji. Wykonane próbki poddano badaniom wytrzymałości na rozciąganie i ściskanie. Analizowano również strukturę wykonanych próbek z zastosowaniem skaningowej mikroskopii elektronowej. Przeprowadzone badania wykazały, że stanowisko do jednoczesnego mieszania i odpowietrzania kompozycji klejowych spełnia stawiane mu oczekiwania. Najkorzystniejszym sposobem mieszania okazał się 4 wariant mieszania, w którym mieszanie zrealizowano z użyciem mieszadła tarczowego dyspergującego. Mieszanie realizowano z prędkością 1170 obr/min w czasie 3 minut. Dodatkowo w trakcie mieszania przeprowadzano process odpowietrzania mieszanej kompozycji, jak również odpowietrzanie realizowano po procesie mieszania w czasie 2 minut. Zmiana parametrów mieszania przyczyniła się do wzrostu wytrzymałości zarówno na rozciąganie, jak i wytrzymałości na ściskanie badanych kompozycji. Analiza SEM obserwowanych próbek wykazała, że zmiana parametrów mieszania pozwala zmniejszyć ilość pęcherzy powietrza w strukturze kleju, a w przypadku kompozycji modyfikowanych spowodowała lepsze rozprowadzenie napełniacza w strukturze mieszanych kompozycji.

Słowa kluczowe: mieszanie, proces klejenia, kompozycja klejowa, SEM

1. Introduction

Bonding technology is a fundamental part of many areas of industry and everyday life. Its importance stems from its ability to combine a variety of materials into durable joints, which contributes to production efficiency, product durability and innovation. The bonding process is a complex technological process that involves several steps. Among the main stages of the bonding process are: preparation of the surfaces of the parts to be joined, selection of the appropriate adhesive, preparation of the adhesive and the method of application, setting and assembling of the parts to be joined, curing of the adhesive joint, inspection of the joints and finishing operations. Various instruments and equipment are often used to carry out both the main bonding steps and the numerous intermediate operations. These are often dedicated special or specialised tools for specific applications.

An extremely important step in the bonding process is the adhesive preparation process, as it affects the quality and performance of the bonding. The correct preparation of the adhesive composition is the key to achieving a durable and reliable joint. The adhesive composition preparation procedure has a direct impact on the degree of dispersion of the composition components in the matrix, as well as on the degree of aeration of the resulting composition. The strength and performance properties of the final material depend on these parameters, so the proper mixing of the adhesive components is critical to the joining process (Godzimirski, 1997; Miturska-Barańska, 2022).

The preparation of an adhesive depends mainly on its form (Cognard, 2006). Structural adhesives in solid or liquid form are usually two or more component compositions, the components of which need to be mixed into homogeneous substances in order to fully perform their functions. In the case of two-component adhesives, care must be taken to ensure that all of its components are properly combined to form a homogeneous adhesive mixture (Axentowicz & Karpiński, 1994; Ebnesajjad, 2008). It is also important to ensure that there are no air bubbles in the adhesive composition, as this is undesirable and can cause non-adhesive bonding of the materials to be bonded, as well as affecting the strength of the adhesive joint (Katnam et al., 2011; Michels et al., 2016). In addition to the basic component, auxiliary substances such as solvents, activators or catalysts for the crosslinking process, curing agents and other additional components are sometimes required. Sometimes, the components of multi-component adhesive compositions include modifying additives, called fillers or modifiers. Primary filler particles in non-agglomerated form are extremely rare under real-world conditions. The occurrence of agglomerates of particles in the matrix can cause defects that result in a reduction in the properties of the modified adhesive, so it is important to select a suitable method of mixing the adhesive composition that will enable the required dispersion of particles to be achieved and their proper wetting by the matrix material (Chikhi et al., 2002; Miturska et al., 2020, 2021). Both manual and mechanical methods are used in the mixing operation, using appropriate tools and equipment. For different types of production, the process can be automated, using appropriate devices, tools or equipment (Rudawska, 2016).

The mixing process for multi-component adhesives is usually carried out using special equipment and stations designed for this purpose. Currently, many design variations of mixers are known. The variety is much greater than for other equipment used in bonding technology (Habenicht, 2009; Kamieński, 2004; Miturska-Barańska, 2022; Rudawska, 2019).

In this paper, the design of a specialised mixing and deaeration station for adhesive compositions is presented. The aim of the study was to present a device for simultaneous mixing and removal of gas bubbles and to verify the correctness of the practical application of the stand by conducting experimental tests. In the experiments, the subject of the study was an adhesive composition of Epidian 5 epoxy resin with

a PAC curing agent, which was prepared using four mixing methods carried out with the use of a stand for simultaneous mixing and deaeration. In addition, the composition was physically modified by adding particles of calcium carbonate $CaCO_3$ to verify the correct mixing of the composition components.

2. Concept and construction of a mixing and deaeration station for adhesive compositions

The paper presents the construction of a mixing and simultaneous deaeration station for multi-component adhesive compositions, in which the most important part is the working part of the station, hereinafter also referred to as the device. A prerequisite for the correct functioning of the station is that the construction and technological requirements affecting the construction and correctness of the adhesive mixing process are met.

2.1. Technological and operational assumptions

The designed device should fulfil specific functions and enable the reproducibility of the adhesive mixing process and, consequently, the reproducibility of the strength properties of the adhesive compositions associated with their manufacturing process. Among the technological and application assumptions adopted, the following can be distinguished:

- the possibility of mixing two or more adhesive components, e.g. resin, modifier and curing agent,
- ensuring that the adhesive mixing process is carried out repeatably,
- that the adhesive composition can be mixed and deaerated at the same time,
- making it possible to adjust the size of the mixing tank,
- that the mixing tank can be quickly cleaned or replaced,
- adaptability to any bench-top drilling machine acting as a mixer drive,
- ease and speed of operation.

The assumptions outlined above have enabled the design of a station that, when used appropriately, will improve the mixing process of adhesive compositions.

2.2. Design assumptions

Figure 1 shows a general schematic of the construction of the described station.

The detailed structure with the main components included in the working part of the adhesive mixing and deaeration device is presented in Figure 2.

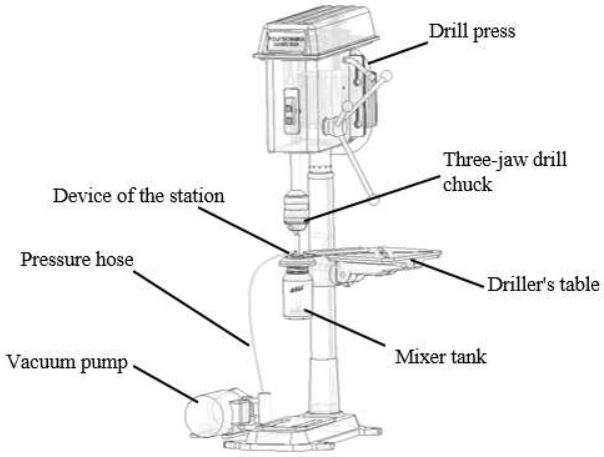

Fig. 1. Schematic overview of mixing and deaeration station for adhesive compositions

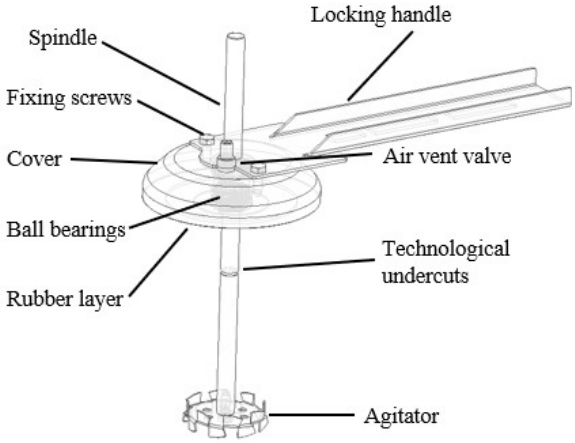

Fig. 2. Construction of a mixing and deaeration device for adhesive compositions

The mixing device consists of a cover in which a spindle is centrally mounted in three identical ball bearings with seals placed parallel to each other. The cover is semi-circular in shape and a vent valve is also fitted into it. A rubber layer is bonded onto the lower surface of the cover to ensure tightness between the cover and the mixed substance tank. The original design concept included the idea of making a thread in the lower part of the lid, the purpose of which would be to fix the mixing tank. However, this solution did not meet the assumption of tightness between the lid and the tank, so that the deaeration process did not proceed correctly. A locking handle, made from a section of sheet metal, is attached to the top of the cover. Rectangular holes are made in the locating handle to allow the handle to be fixed to the drill table. Technological undercuts are made on the spindle to allow the length of the agitator to be locked in place with a circlip. An agitator of any shape is screwed onto the lower part of the spindle. The design of the unit makes it compatible with any type of drill press

equipped with a three-jaw self-clamping chuck, so it is characterised by its ability to be quickly mounted and dismounted. The design of the device also allows the agitator to be changed depending on the properties of the adhesive composition to be mixed.

Among the design considerations of the adhesive mixing and deaeration device, it was assumed that the adhesive mixing tank is made of glass, so that it is not exposed to the negative pressure created when deaeration the composition as are commonly available tanks made of plastic. The cover was made of aluminium alloy, while the other components were made of stainless steel, making it possible to wash all components with cleaning agents.

2.3. Operation of the device for simultaneous mixing and deaeration of the adhesive composition

The operation of the adhesive composition mixing and deaeration device is based on fastening the locating handle to the drill table using a screw. The spindle, on the other hand, is fixed in a self-clamping drill chuck. The design of the device allows the spindle to rotate at the speed set in the drill settings. A air vent valve fitted in the cover allows the mixed substances to be deaerated, also during the mixing process by connecting to the vacuum pump via a pressure hose. The technological undercuts on the spindle make it possible to adjust the working length of the spindle and the agitator mounted on it by means of a locking ring, depending on the size of the tank in which the mixing process is carried out. The size of the tank, on the other hand, depends on the amount of substance to be mixed. The vessel must be supported during mixing, as it is only held by the vacuum applied.

3. Experimental studies

In order to verify the correctness and validity of the presented station for simultaneous mixing and deaeration of adhesive compositions, experimental tests were carried out. Within the scope of these tests, adhesive compositions were prepared using 4 mixing variants differing in terms of the parameters used, which were then subjected to strength tests

3.1. Materials used in the study

Epidian 5 epoxy resin and PAC curing agent were used to make the adhesive compositions. In addition, modified adhesive compositions were also produced, to which 5% $CaCO_3$ calcium carbonate was added, in order to check the distribution of the modifier particles in the adhesive structure when using different mixing variants.

The matrix function in the tested adhesive compositions was performed by the Epidian 5 epoxy resin. This is a pure form of epoxy resin, which is a product of the reaction of bisphenol A with epichlorohydrin. It has excellent adhesion to most plastics, chemical resistance, as well as resistance to aggressive environmental factors and good electrical properties (*BN- 89 6376-02*; *Information catalogue of Ciech S.A.*, Czub & Penczek, 2002; Yoon et al., 2011). Epidian 5 epoxy resin and compositions based on it are used in the manufacture of fibreglass laminates, bonding metals, ceramics and thermosetting plastics. Adhesives prepared on the basis of this resin are also used in building structures as anti-corrosion and electro-insulating coatings.

The curing agent used in the study was polyamide PAC curing agent. PAC curing agent is a mixture of fatty acids, C18-unsaturated, dimers, polymeric reaction products with triethylenetetramine. It is used to cure liquid epoxy resins. This curing agent increases the elasticity and impact strength of the composition and is therefore used for joints subject to deformation. The PAC curing agent belongs to the group of slow-reacting hardeners and, as an indication, its use time can be taken at room temperature - 180 minutes. This is followed by an initial hardening in a further 6-8 hours to achieve an approx. 80-90% hardening after 72 hours. Complete curing is achieved after 7-14 days.

The basic physical and chemical properties of the adhesive components used are summarised in Table 1.

Table 1. Physical and chemical properties of the adhesive compositions components used in the study (Bereska et al., 2014; *BN-89 6376-02*; *Information catalogue of Ciech S.A.*; Czub & Penczek, 2002; Królikowski & Rosłaniec, 2004)

Properties	Epidian 5 epoxy resin	PAC curing agent
Epoxy number (resin) / Amine number (curing agent)	0.48 – 0.52 mol/100 g	290 – 360 mg KOH/g
Viscosity at 25ºC	20 000 – 30 000 mPa·s	10 000 – 25 000 mPa·s
Density at 20°C	1.16 g/cm^3	1.10 – 1.20 g/cm^3

The filler used in the study was $CaCO_3$ calcium carbonate. The calcium carbonate used in the study was produced by Zakłady Przemysłu Wapienniczego Trzuskawica S.A. in Siatkówka and has a molecular weight of 100.09 g/mol with particle size ≤ 5 μm (at least 99%). The typical concentration of $CaCO_3$ is 98.23%, while the concentration range is between 92-99%. Calcium carbonate is widespread in nature, being a basic component of many minerals (e.g. calcite and aragonite), as well as some rocks (dolomite, chalk and coral). The use of chalk as a modifying additive in appropriate proportions, which according to the literature (He i in., 2011; Jin & Park, 2008; Kacperski, 2004; Park, Su-Jin, 2009; Zebarjad & Sajjadi, 2008)

are in the range of 2-8 parts by weight, alters certain physical properties. The use of calcium carbonate $CaCO_3$ in adhesive compositions allows, among other things: to increase bending strength (Kacperski, 2004; Miturska i in., 2020), to increase impact strength (Miturska et al., 2021; Miturska & Rudawska, 2020) and to improve the thermal stability of the composition (Park, Su-Jin, 2009; Zebarjad & Sajjadi, 2008).

In the tests, the adhesive compositions were mixed in the appropriate weight ratios. For 100 parts by weight of resin, 80 parts by weight of curing agent were introduced. In the case of modified compositions, the epoxy resin and modifier were mixed in the first step at a ratio of 5 parts by weight per 100 parts by weight of resin, followed by the addition of the curing agent.

Weighing of the components of the adhesive compositions was done using a KERN CKE 3600-2 laboratory balance with a measurement accuracy of ±0.01 g.

3.2. Variants for mixing adhesive compositions

The mixing method of adhesive compositions significantly affects the strength properties of the compositions produced. In the course of achieving the stated aims of the study, four mixing methods were used (Table 2).

Table 2. Parameters of the mixing variants

Mixing variant	Description of the mixing process
V1	Mixing with paddle agitator: - speed 1170 rpm, - time: 3 min.
V2	Mixing with dispersing disc agitator: - speed 1170 rpm, - time: 3 min.
V3	Mixing with dispersing disc agitator: - speed 1170 rpm, - time: 3 min. Deaeration of the composition during mixing.
V4	Mixing with dispersing disc agitator: - speed 1170 rpm, - time: 3 min. Deaeration of the composition during mixing. Deaeration of the composition after the mixing process: - time: 2 min.

Mixing of the composition was carried out using two types of agitator, differing in geometry. The first was a paddle mixer, the geometry of which is shown in Figure 3. The second type of agitator, was a dispersing disc agitator with holes and trapezoidal teeth, which geometry is presented in Figure 4.

The mixers were made according to the standards in force in this area (*BN-72/2222-06*; *BN-75/2225-06*; *BN-75/2225-07*; Miturska-Barańska, 2022), so that the dimensions of the mixers were appropriate in relation to the tank in which the adhesive compositions were mixed.

Fig. 3. Blade agitator used in the study

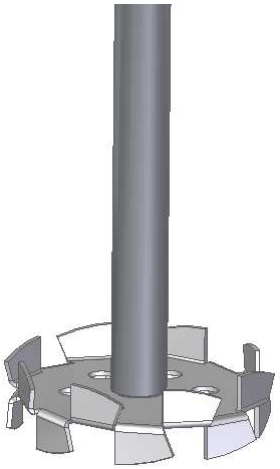

Fig. 4. Dispersing disc agitator used in the tests

Deaeration of the compositions during mixing was made possible by a valve fitted into the cover of the composition mixing and deaeration device. Venting was carried out using a CPS model VP6D two-stage vacuum pump.

Mixing was carried out by adapting an OPTIMUM B20 drill press. Mixing was carried out in a glass jar, thus avoiding the reaction that could occur if the composition was mixed in a tank made of polymer plastic. In addition, the glass jar facilitates thorough mixing and the deaeration process during mixing of the compositions.

After the adhesive compositions were prepared using appropriate moulds, samples of standardised dimensions were cast (Broniewski et al., 2000; *ISO 604*; *PN-EN ISO 527-1*). The geometry of the samples used during the tests is shown in Figures 5 and 6. For each composition and each mixing variant, 5 samples were prepared for testing.

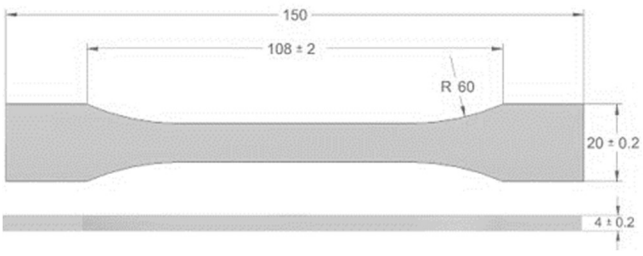

Fig. 5. Shape and dimensions of adhesive compositions sample for tensile strength testing

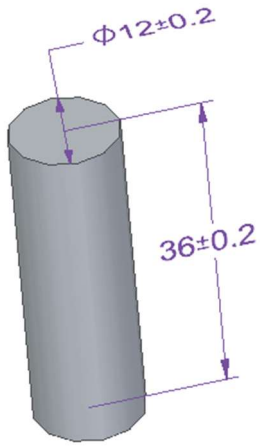

Fig. 6. Shape and dimensions of the cylindrical sample of adhesive compositions for the compressive strength tests

Samples of the epoxy adhesive compositions were prepared at a temperature of 23°C ± 2°C at an air humidity of 23% ± 3%, followed by a one-step cold curing process for a period of 7 days under unchanged conditions.

3.3. Results of strength tests

After the curing time, the samples were subjected to strength tests. Tensile and compressive strengths were tested. The tests were carried out on a Zwick/ Roell Z150 testing machine. In the tensile strength test, the crosshead travel speed during the test was 5 mm/min. For the compressive strength test, the crosshead speed used during the test was 10 mm/min. The results obtained are shown in the figure below (Fig. 7, Fig. 8).

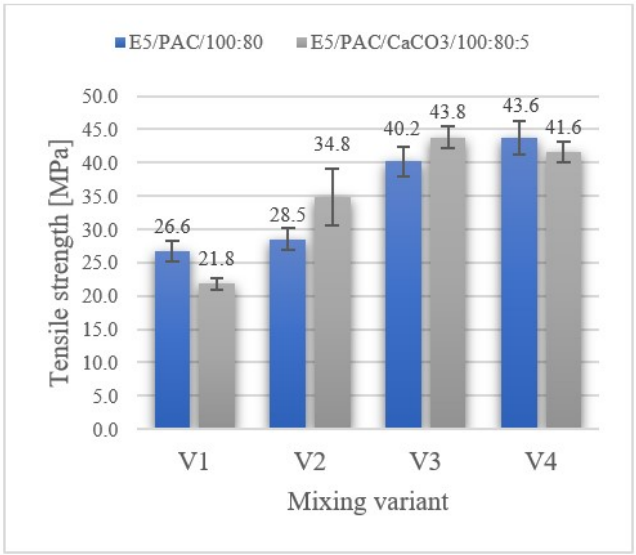

Fig. 7. Tensile strength of adhesive compositions

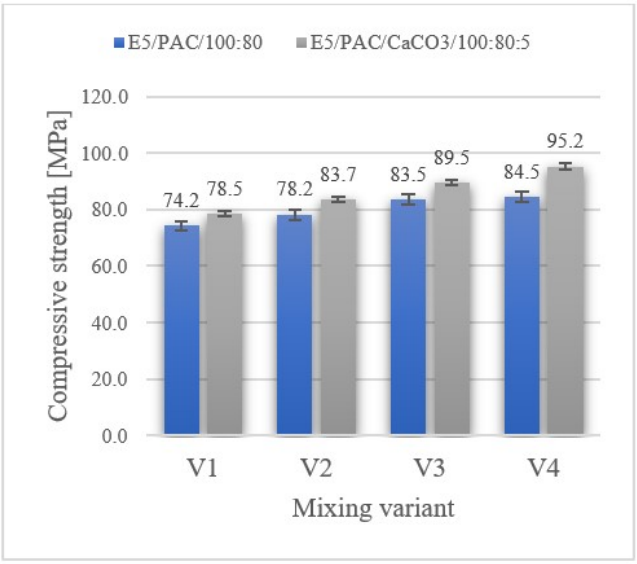

Fig. 8. Compressive strength of adhesive compositions

Due to the similar values in several groups of results obtained, a statistical analysis was carried out at a further stage of the analysis of the test results obtained. The assumption of normality of distribution for tensile strength was tested. The results of this test are summarised in Table 3.

Table 3. Normality test results for tensile strength

Adhesive composition	Mixing variant	W^2	p^2
E5/PAC/100:80	V1	0 .9827	0 .9484
E5/PAC/100:80	V2	0 .9827	0 .9484
E5/PAC/100:80	V3	0 .9827	0 .9484
E5/PAC/100:80	V4	0 .9827	0 .9484
E5/PAC/$CaCO_3$/100:80:5	V1	0 .9340	0 .6241
E5/PAC/$CaCO_3$/100:80:5	V2	0 .7050	0 .0108
E5/PAC/$CaCO_3$/100:80:5	V3	0 .9340	0 .6241
E5/PAC/$CaCO_3$/100:80:5	V4	0 .9340	0 .6241

[1] Statistical value W Shapiro-Wilk test
[2] Level p for the Shapiro Wilk test

From the results obtained, it can be seen that for the Shapiro-Wilk W-test, the p-value is not greater in all groups than the accepted significance level of $\alpha = 0.05$ and therefore it must be assumed that the distribution does not follow a normal distribution. Therefore, non-parametric statistics parameters were used to further analyse both tensile strength and compressive strength. A post-hoc test was then performed to determine significant differences between the different groups of samples tested. The results of this test are presented in Tables 4-7.

Table 4. Results of post-hoc test of significant differences in average tensile strength depending on mixing variant - E5/PAC/100:80 adhesive composition

	Tukey's HSD test; Approximate probabilities for post hoc tests Error: MS between-group = 4.1733, df = 16.00				
No.	**Mixing variant**	{1} 26.645	{2} 28.465	{3} 40.161	{4} 43.637
1	V1		0.5122	0.0002	0.0002
2	V2	0.5122		0.0002	0.0002
3	V3	0.0002	0.0002		0.0692
4	V4	0.0002	0.0002	0.0692	

Table 5. Results of post-hoc test of significant differences in average tensile strength depending on mixing variant - E5/PAC/$CaCO_3$/100:80:5 adhesive composition

	Tukey's HSD test; Approximate probabilities for post hoc tests Error: MS between-group = 6.0127, df = 16.00				
No.	**Mixing variant**	{1} 21.823	{2} 34.764	{3} 43.803	{4} 41.620
1	V1		0.0002	0.0002	0.0002
2	V2	0.0002		0.0003	0.0023
3	V3	0.0002	0.0003		0.5131
4	V4	0.0002	0.0023	0.5131	

Table 6. Results of post-hoc test of significant differences in average compressive strength depending on mixing variant - E5/PAC/100:80 adhesive composition

	Tukey's HSD test; Approximate probabilities for post hoc tests Error: MS between-group = 3.5631, df = 16.00				
No.	**Mixing variant**	{1} 74.237	{2} 78.189	{3} 83.516	{4} 84.547
1	V1		0.0208	0.0002	0.0002
2	V2	0.0208		0.0021	0.0005
3	V3	0.0002	0.0021		0.8233
4	V4	0.0002	0.0005	0.8233	

Table 7. Results of post-hoc test of significant differences in average compressive strength depending on mixing variant - E5/PAC/$CaCO_3$/100:80:5 adhesive composition

	Tukey's HSD test; Approximate probabilities for post hoc tests Error: MS between-group = 1.1453, df = 16.00				
No.	**Mixing variant**	{1} 78.505	{2} 83.670	{3} 89.523	{4} 95.205
1	V1		0.0002	0.0002	0.0002
2	V2	0.0002		0.0002	0.0002
3	V3	0.0002	0.0002		0.0002
4	V4	0.0002	0.0002	0.0002	

Values marked in red indicate that there are significant differences between the analysed groups at a significance level of $p < 0.05$. Analysing the results obtained, it can be observed that, in the case of tensile strength, mixing variants 3 and 4 were significantly different from mixing variants 1 and 2 for both the basic and modified compositions. A similar distribution of results can be observed for the compressive samples. This indicates that changing the mixing conditions significantly affects the properties of the adhesive compositions.

3.4. SEM tests of adhesive compositions

The structure of the analysed adhesive compositions in the cured state was also studied by scanning electron microscopy (SEM) in order to assess the effect of the mixing method on the structure of the resulting composition. Figures 9-14 show SEM micrographs of the compositions studied.

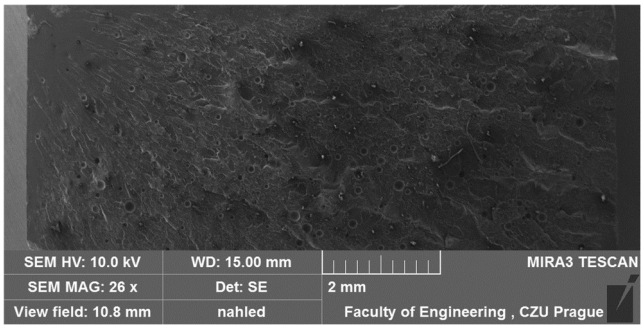

Fig. 9. SEM micrograph of unmodified E5/PAC/100:80 adhesive composition, 1st mixing variant

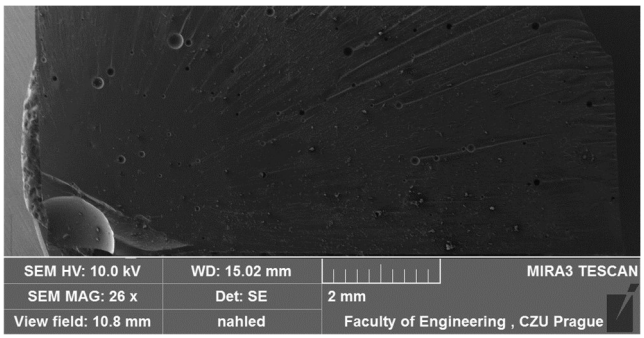

Fig. 10. SEM micrograph of unmodified E5/PAC/100:80 adhesive composition, 4th mixing variant

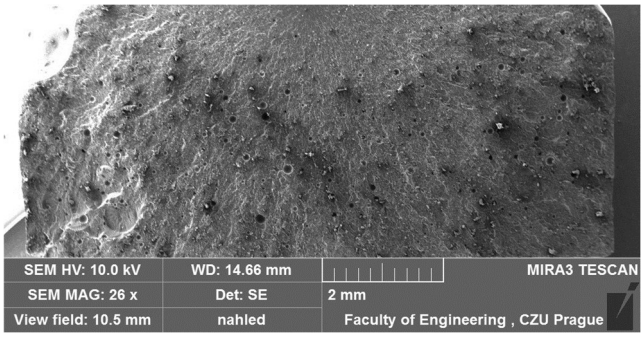

Fig. 11. SEM micrograph of E5/PAC/$CaCO_3$/100:80:5 adhesive composition, 1st mixing variant

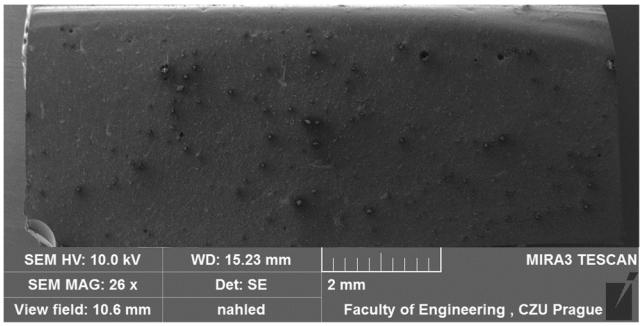

Fig. 12. SEM micrograph of E5/PAC/$CaCO_3$/100:80:5 adhesive composition, 4th mixing variant

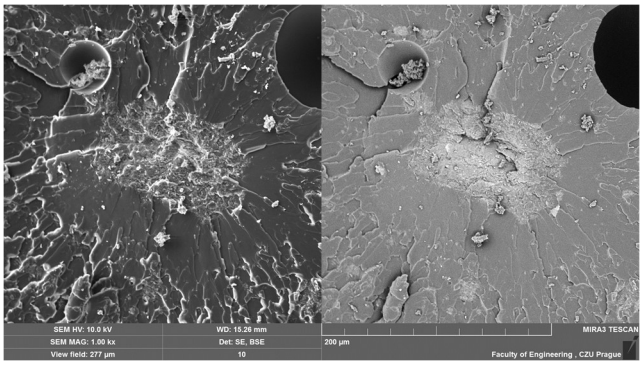

Fig. 13. SEM micrograph of E5/PAC/$CaCO_3$/100:80:5 adhesive composition, 1st mixing variant

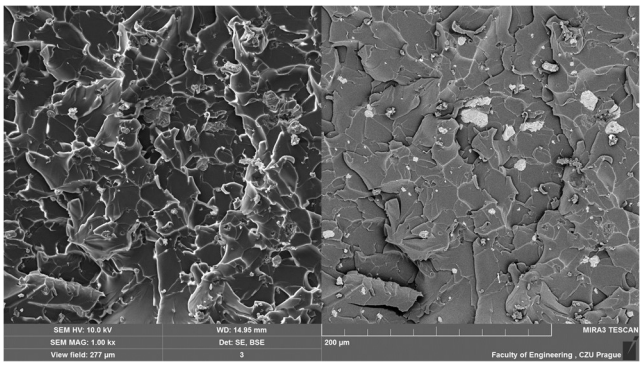

Fig. 14. SEM micrograph of E5/PAC/$CaCO_3$/100:80:5 adhesive composition, 4th mixing variant

The presented SEM microphotographs of the tested adhesive compositions show that the process of deaeration of the composition allows the amount of gas bubbles present in the structure of the composition to be significantly reduced. Based on the photographs shown in Figure 10, it can be seen that the unmodified E5/PAC/100:80 adhesive composition mixed with the mixing variant 4 is characterised by a homogeneous, solid structure. Few gas bubbles are visible on the surface. In the case of the reference composition, the breakthrough is soft and malleable.

Analysing the SEM micrographs of E5/PAC/$CaCO_3$/100:80:5 modified composition prepared using mixing variant 4, good wettability at the filler-matrix interface can be observed, which is due to the interaction of the filler with the matrix (Fig. 14). It can also be observed that there are fewer filler agglomerates, i.e. better distribution in the structure of the mixed composition compared to the modified composition prepared using mixing variant 1 shown in Figure 13.

4. Summary and conclusions

This paper presents the design of a specialised station for mixing and venting adhesive compositions.

The research carried out shows that the station for simultaneous mixing and deaeration of adhesive compositions meets the expectations set for it. The application of mixing methods using the capabilities of the designed stand (4th mixing variant), contributed to:

- An increase in tensile strength by 39% for the unmodified composition compared to compositions prepared using the basic mixing method (mixing variant 1).
- An increase in tensile strength by 47.6% for the composition modified with 5% $CaCO_3$ calcium carbonate compared to compositions prepared using the basic mixing method (mixing variant 1).
- An increase in compressive strength by 12.2% for the unmodified composition compared to the compositions prepared using the basic mixing method (mixing variant 1).
- An increase in compressive strength by 17.5% for the composition modified with 5% $CaCO_3$ calcium carbonate compared to compositions prepared using the basic mixing method (mixing variant 1).
- A reduction in the amount of gas bubbles in the structure of the cured adhesive compositions, which can be observed by comparing the SEM micrographs shown in Figures 9 and 10, in the case of unmodified compositions - E5/PAC/100:80, and in Figures 11 and 12 in the case of compositions modified with calcium carbonate - E5/PAC/$CaCO_3$/100:80:5.
- A better distribution of the filler in the structure of the mixed compositions, as can be observed by comparing the SEM micrographs in Figures 13 and 14.

However, there are still a few gas bubbles in the adhesive structure. Perhaps extending the deaeration time would allow air bubbles to be completely removed from the adhesive, which could then have a positive effect on improving the strength properties of the adhesive joints and improving the quality of the adhesive joints.

The station designed and described in the paper has several advantages. These include:

- simple and functional design,
- ease and simplicity of operation,
- easy mixer replacement,
- the possibility of using mixers with different geometries,
- compatibility with various models of drill press acting as agitator drive,
- mixing speeds can be varied to match the capacity of the drive unit,
- possibility to mix two-component adhesives, as well as adhesives consisting of several components,
- small overall dimensions,
- construction in stainless steel and aluminium alloys eliminates the possibility of component corrosion,
- simple construction allows quick cleaning of the device,
- easy replacement of the mixer tank,
- possibility to adjust the length of the mixer to tanks with smaller and larger capacities, and thus the possibility to mix the appropriate amount of adhesive composition at one time.

The stand for simultaneous mixing and deaeration of adhesive compositions also has some limitations, although they are few compared to its advantages. Chief among these limitations is the inability to heat the adhesive or adhesive composition components during mixing.

In conclusion, the designed station fully meets the expectations set for it, and the simple design allows the station to be adapted both in laboratory, workshop and production spaces.

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