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PRELIMINARY ANALYSIS OF CONCEPT OF PRODUCING POLYMER CONCRETE SURFACE FOR OUTDOOR TERRACES

The aim of this study is to assess the possibility of using an innovative two-layer polymer concrete system as a complete outdoor terrace surface. The work is a preliminary technical study. For the purpose of the work, two samples differing in aggregate used were produced. One of them was filled with a mixture of gravel (coarse grain) and sand (fine grain) aggregate, the other was filled only with gravel (coarse grain) aggregate. The assessment methodology was based on simple tests of selected basic functional characteristics, which were load resistance, abrasion resistance, water absorption, and resistance to dirt. The obtained results of the evaluation of the produced materials indicate that the concept of using a two-layer polymer concrete system as an external surface is good - the material shows satisfactory behavior both in terms of static and frictional loading, and in terms of water drainage. Polymer concrete with coarse grained aggregate is visually attractive after application, but also susceptible to dirt, which is difficult to remove by simple methods. Hence, it is are difficult to keep clean and aesthetic. Polymer concrete with aggregate containing a fine fraction is easier to keep clean and aesthetic, but it is not as visually attractive as the concrete filled only with the coarser grained aggregate. The applied additional resin protective coating significantly improves the effectiveness of removing dirt from the surface. However, for a coarse-grained surface, the improvement in cleaning performance is probably insufficient. According to the two-layer concept, polymer concrete is an attractive and real alternative material for outdoor terraces. The potential proposal of a two-layer polymer concrete as a terrace surface requires a number of further development works, mainly in terms of the optimization of aesthetics, cleanability and analysis of the issue of water absorption and water freezing inside the material structure.

Keywords: polymer concrete, outdoor terrace

WSTĘPNA ANALIZA KONCEPCJI WYTWORZENIA POLIMEROBETONOWEJ NAWIERZCHNI TARASU ZEWNĘTRZNEGO

Celem niniejszego studium jest ocena możliwości zastosowania innowacyjnego dwuwarstwowego systemu polimerobetonu jako kompletnej nawierzchni tarasu zewnętrznego. Praca ma charakter wstępnego studium technicznego. Na potrzebę pracy wytworzono dwie próbki różniące się użytym kruszywem. Jedna z nich została napełniona mieszaniną kruszywa żwirowego (gruboziarnistego) oraz piaskowego (drobnoziarnistego), druga została napełniona tylko kruszywem żwirowym. Metodykę oceny oparto na prostych próbach wybranych podstawowych cech użytkowych, jakimi były: odporność na obciążenie, odporność na ścieranie, pochłanianie wody, odporność na zabrudzenie. Uzyskane wyniki oceny wytworzonych materiałów wskazują, że koncepcja zastosowania dwuwarstwowego układu polimerobetonowego jako nawierzchni zewnętrznej jest dobra – materiał pokazuje zadowalające zachowanie zarówno pod kątem obciążania statycznego i ciernego, jak i pod kątem odprowadzania wody. Polimerobetony z kruszywem o grubszym uziarnieniu są po nałożeniu atrakcyjne wizualnie, ale też podatne na zabrudzenia, które trudno z nich usunąć prostymi metodami. Są więc trudne w utrzymaniu czystości i estetyki. Polimerobetony z kruszywem zawierającym frakcję drobną są łatwiejsze w utrzymaniu czystości i estetyki, ale nie tak atrakcyjne wizualnie, jak te napełnione tylko kruszywem grubszym uziarnieniu. Nałożona żywiczna powłoka ochronna znacząco poprawia skuteczność usuwania brudu z nawierzchni. Dla nawierzchni gruboziarnistej poprawa skuteczności czyszczenia jest prawdopodobnie niewystarczająca. Polimerobetony według koncepcji dwuwarstwowej są atrakcyjnym i realnym alternatywnym materiałem na tarasy zewnętrzne. Potencjalne zaproponowanie dwuwarstwowego polimerobetonu jako nawierzchni tarasowej wymaga szeregu dalszych prac rozwojowych, głównie pod kątem optymalizacji estetyki, podatności na czyszczenie oraz analizy kwestii pochłaniania i zamarzania wody wewnątrz struktury.

Słowa kluczowe: polimerobeton, taras zewnętrzny

INTRODUCTION

Polymer concretes are composite materials in which the matrix is a curable resin, and the reinforcing phase, present in an amount even exceeding 80% by volume, is a properly composed mineral aggregate [1, 2]. These materials are widely used for building facades [3, 4], elements of street drainage [5], or internal linings of water and sewage pipes [6]. They are also widely used for road repair and renovation [7, 8]. Polymer concrete technology also allows the management of mineral waste [9], as well as ashes and other waste after industrial combustion [10]. Polymer concrete technology is relatively simple and is based on the use of dedicated components, primarily appropriate curable resins [11]. The use of resins is also the most problematic element of this technology. In particular, curing large portions of resin at once is a difficult task, requiring care and keeping a time regime [12, 13]. The main advantages of polymer concretes are: chemical resistance, crack and impact resistance, durability and physical stability.

One of the applications for polymer concretes, which are widespread but still have a significant application and innovative potential, are widely understood utility surfaces. It concerns both internal floors – home and industrial [14] – but also external surfaces [15]. When it comes to polymer concrete, one of the undeveloped areas is outdoor terraces.

In the case of private residential buildings, outdoor terraces are most often made of wooden boards or composite thermoplastic-shredded wood component panels [16]. In the case of public or industrial facilities, external terrace surfaces are most often concrete or made of ceramic tiles [17]. Each of these materials has its own advantages and disadvantages. The disadvantages typical for composites based on thermoplastics, also affecting terrace boards are the susceptibility to scratching - especially when the material is hot, e.g. from the sun, but also for instance from a shovel for snow removal, discoloration under the influence of UV (Fig. 1a), as well as the susceptibility to become permanently dirty. Damage to a composite terrace may also arise due to the rheological effects occurring in the composite – mainly creep bending of the boards, especially in high insolation (see Fig. 1b). Boards may also twist due to high shrinkage and thermal expansion. In general, the spontaneous deformation of composite boards may occur after several years of use. In the case of wood, the need for regular maintenance must be faced. This is cumbersome in the long term, especially for large surfaces. However, even proper maintenance does not completely protect against the effects of weathering and cracking of the wood, which entail a significant reduction in aesthetics (Fig. 1c).

As for concrete surfaces, in the classic version they are characterized by poor aesthetics and susceptibility to dirt and weathering. The more aesthetic version, ground and polished, is very expensive and slippery, as well as exposed to weathering. Ceramic tiles are usually quite durable (provided that appropriately high-quality tiles are selected, which is also associated with a high price). However, the main problem is the limited durability of the bond between the tiles and the ground material, as well as the susceptibility to cracking under impact.

Taking into account the disadvantages of practically every type of material used for terraces, it was decided to initiate an attempt to supplement the existing range of materials with polymer concrete. It is difficult to call polymer concretes new materials, but it should be emphasized that they are not currently used commercially for terrace surfaces. If they are used as exterior paving materials, in most cases, due to the cost of the materials, only relatively thin exterior layers are made on another hard substrate. As part of this work, it was decided to try such a new approach.

The aim of this study is to assess the possibility of using an innovative two-layer polymer concrete system as a complete exterior terrace surface. Polymer concrete in the proposed form could be used for private, public and industrial terraces. The work is a preliminary technical study, therefore it was based on simple methods of assessing selected basic features of two alternative types of produced samples. Further research will depend on the evaluation of the obtained results in terms of commercial applicability.

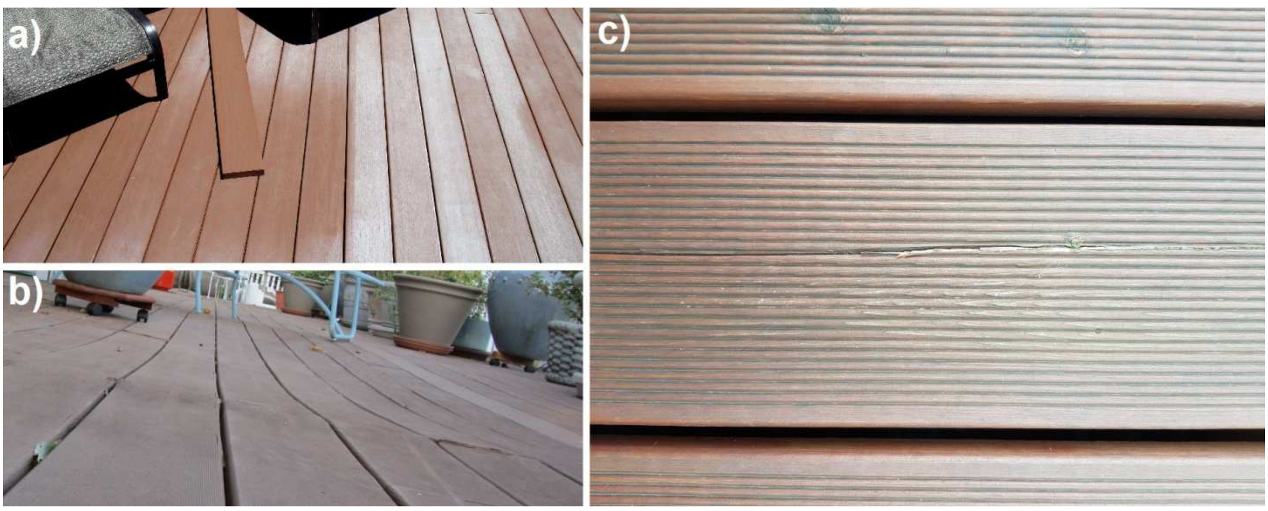

Fig. 1. Illustrated functional defects of surface of terrace elements: a) composite board – discoloration [18], b) composite board – deformation [19], c) Siberian larch wood board – crack along main fibers [source: authors' own documentation]

Rys. 1. Zobrazowane wady użytkowe nawierzchniowych elementów tarasowych: a) panel kompozytowy – odbarwienie [18], b) panel kompozytowy – deformacja [19], c) panel drewniany modrzew syberyjski – pęknięcie wzdłuż głównych włókien [źródło: dokumentacja własna]

PREPARATION OF MATERIALS

In order to achieve the aims of the study, two polymer concrete samples were prepared according to two alternative assumptions - in the following part of the work they will be called "sample 1" and "sample 2", respectively. Both samples were 500 x 500 mm in size and approximately 65 mm thick. Both were also prepared according to the original concept of two layers – the bottom base layer and the aesthetic top layer. Figure 1 shows the aggregates used. For sample 1, the base layer was based on an aggregate consisting of a mixture of coarse quartz gravel of a mixed color and a declared granulation of 2÷8 mm, and quartz sand also of a mixed color and a declared granulation 0.1÷0.2 mm (Fig. 2a). Sample 2 had a gravel base layer of 2÷8 mm only (Fig. 2d). Sample 1, as filling of the top layer, had a mixture of segregated, high-quality white gravel, granulation 1÷5 mm, and high-quality quartz sand, granulation 0.1÷0.4 mm, also white (Fig. 2b). Sample 2 had the top layer filled only with the 1÷5 mm white high quality gravel (Fig. 2c). Generally, sample 1 is gravel/sand filled polymer concrete and sample 2 is gravel filled polymer concrete without a sand sealing fraction.

a) b) c) d)

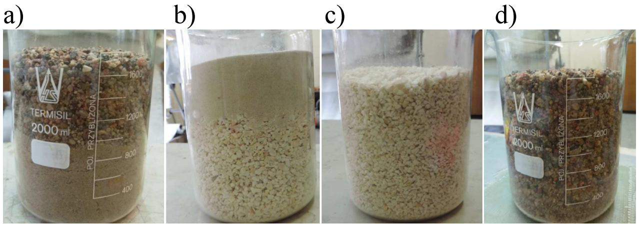

Fig. 2. Mixtures of aggregates for preparing polymer concrete masses: a) sample 1 mass for base layer, b) sample 1 mass for top layer, c) sample 2 mass for top layer, d) sample 2 mass for base layer

Rys. 2. Mieszanki kruszyw do sporządzania mas polimerobetonowych: a) próbka 1 masa dla warstwy podkładowej, b) próbka 1 masa dla warstwy wierzchniej, c) próbka 2 masa dla warstwy wierzchniej, d) próbka 2 masa dla warstwy podkładowej

The gravel used for the top layers was pre-washed with water. About 7.5 g of impurities were removed from it per 1 kg of its initial mass. All the aggregates were dried in free air inside a closed room for 72 hours. Additionally, the aggregates intended for the top layers were dried in an oven for 2 hours at the temperature of 100°C.

The matrix for the base layer in both the manufactured boards was the polyester resin Estromal 14LM (LERG, Poland), catalyzed by the initiator Metox 50 (Oxytop, Poland), added in the amount of 1.5% by weight of the resin. The matrix for the surface layer in both the boards was epoxy resin LH288 + hardener H505 by HAVEL COMPOSITES, Czech Republic, with excellent transparency and low viscosity (it was decided to use such a resin for the preliminary tests to facilitate the process of concrete preparation in laboratory conditions and to ensure that the matrix did not affect the aesthetics of the concrete. Undoubtedly, for commercial purposes, at further stages of research, a much cheaper resin should be selected). The compositions of both prepared samples are given in Table 1.

TABLE 1. **Composition of polymer concrete samples produced for purpose of research**

TABELA 1. **Składy próbek polimerobetonów wyprodukowanych na potrzebę badań**

Component/Komponent	Sample 1/Płyta 1	Sample 2/Płyta 2
Low quality gravel – base layer (żwir niższej jakości – warstwa podkładowa) [kg]	5.10	15.30
Low quality sand – base layer (piasek niższej jakości – warstwa podkładowa) [kg]	10.20	-
High quality gravel – top layer (żwir wysokiej jakości – warstwa wierzchnia) [kg]	2.04	2.04
High quality sand – top layer (piasek wysokiej jakości – warstwa wierzchnia) [kg]	3.91	-
Polyester resin (żywica poliestrowa) Estromal 14 LM – base layer (warstwa podkładowa) [kg]	2.00	2.00
Catalyst (inicjator) Metox 50 – base layer (warstwa podkładowa) [kg]	0.03	0.03
Epoxy resin (żywica epoksydowa) LH288 – top layer (warstwa wierzchnia) [kg]	0.60	0.60
Hardener (utwardzacz) H505 – top layer (warstwa wierzchnia) [kg]	0.15	0.15

In the case of the gravel-sand mixtures, according to the theory of polymer concrete [1], the filling factor was above 87%, which meets all the optimization standards for the selection of aggregates. When using only gravel, the fill factor was estimated at 80%, which, with the resin content used (above 20%), theoretically also ensures that the entire volume of the molded board is filled. For the aggregate stacks used, the priority was not to meet the theoretical requirements, but the main focus was on aesthetics (the top layers) and easy commercial availability of the aggregates (their common character), and the lowest possible price.

The concrete mass casting molds were assembled from chipboard in the form of open square boxes. Several layers of release agent wax were applied to the inner surfaces of the boxes (mold cavities).

The resin with the appropriate aggregate was mixed with an electric stirrer until a homogeneous consistency was obtained. The hardener or initiator (depending on the type of resin) was added to the mixed mass and mixing was continued.

The sample was formed by pouring out the entire mass and spreading it evenly over the mold using a wooden scraper. Then, the mass of the top layer was poured over the hardened base layer and it was also evenly distributed using a scraper – photographs from the molding process are shown in Figure 3. Additionally, for the purpose of the planned tests, before the surface mass had cured, a gutter was formed in it to drain water by pressing a metal smooth rod into the mass (Fig. 3c).

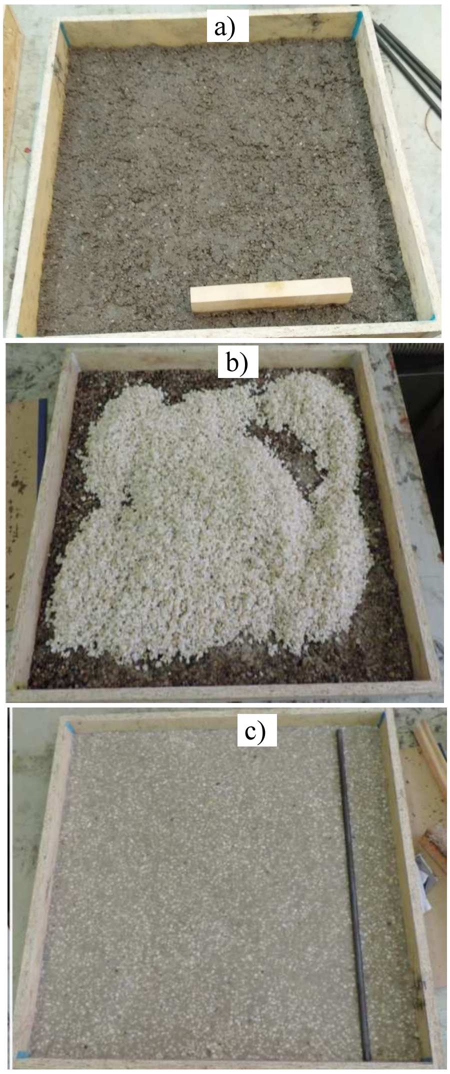

Fig. 3. Forming samples from polymer concrete: a) base layer during leveling, b) mass of top layer applied to pre-cured base layer, c) forming water drainage gutter using metal rod

Rys. 3. Formowanie próbek z polimerobetonów: a) warstwa podkładowa podczas wyrównywania, b) masa warstwy wierzchniej nałożona na wstępnie utwardzoną warstwę podkładową, c) formowanie rynienki odprowadzającej wodę przy pomocy metalowego pręta

After shaping and curing the polymer concrete, two samples were obtained that differed significantly in the appearance of the surface. The sample with only gravel as the aggregate (Fig. 4a) showed undoubtedly better aesthetics than the sample with the addition of sand. The sand, although it was white in color, after hardening the resin forms a homogeneous mass with a beige shade (Fig. 4b).

At the same time, the surface of the sand-containing sample is much smoother and tighter than the gravel sample. The cured boards were left in free air in a closed room for 18 days before the planned tests were carried out on them.

Fig. 4. Surfaces of hardened polymer concrete produced as part of the work: a) only gravel aggregate, b) gravel-sand aggregate

Rys. 4. Nawierzchnie utwardzonych polimerobetonów wytworzonych w ramach pracy: a) kruszywo wyłącznie żwirowe, b) kruszywo żwirowo-piaskowe

As for the polymer concrete sample manufacturing process, it is theoretically simple. In practice, thorough mixing of the aggregate with the resin was not easy and required at least a few minutes – for a mass amount of approx. 10 kg. It should also be remembered that the mass is be precisely mixed with the hardener/initiator. It is particularly difficult when epoxy resin and hardener are used, where the hardener constituted 1/5 of the volume of the entire liquid phase, and its absence in the first stage of mixing additionally slowed down the process. Extending the mixing and subsequent pouring and leveling process may result in premature curing. The fact that the resin curing time depends on the volume of its portion should be particularly taken into account – the process is faster for larger volumes [12, 20]. In the activities carried out as part of the work, all the processes were successfully completed; however, activities on an industrial scale, on larger volumes of hardened mass, must be properly optimized.

Another issue on which the properties of the composite depend, including polymer concrete, is the connection of the matrix with the reinforcement. It is always difficult to obtain a good connection with a large physical and chemical diversity of components [21]. Nonetheless, the relatively high specific surface area of the aggregate particles in the polymer concrete, combined with the relatively simple requirements of the mechanical properties, limits this problem. Yet another issue is to obtain adequate homogeneity. During intensive mixing in composites with particles, phase segregation may occur, e.g. by percolation [22]. In polymer concrete it is an undesirable phenomenon as it disturbs the uniformity of the volume fraction and may, for example, cause local susceptibility to cracking. However, there is no problem of gravity separation (sedimentation) because the viscosity of a well-prepared mass is too high and the hardening time is too short to allow a significant influence of this process. Yet another issue is the air adsorbed in the polymer concrete mass. The elimination of adsorbed gas is a very complicated procedure, especially if achieving high accuracy is intended [23, 24], which is practically not applicable for large amounts of polymer concrete prepared in field conditions. The presence of gas in the structure of polymer concrete should be accepted and taken into account when designing the properties of the material.

TESTS AND RESULTS

The manufactured boards were subjected to simple functional tests aimed at assessing three main features: mechanical resistance, tightness, and susceptibility to dirt. As the research is preliminary, proprietary non-standardized testing methods were used.

The advantage of this type of tests is the simplicity of implementation – even micro-entrepreneurs can do them on their own, contrary to standardized tests that they would have to commission from a research center, which would be expensive and time consuming. Of course, non-standardized tests are only suitable for low-liability applications (e.g. the terrace of a detached house), where a small company takes responsibility for the quality and gives its own guarantees. Such non--standardized tests are sufficient to confirm the quality of this type of product and do not pose a serious financial challenge for a micro-enterprise. For example, in Poland most terraces of single-family houses are made by micro and small businesses.

The first stage of evaluating the manufactured samples was to assess the mechanical properties. The simplified methodology included two types of tests: a simple loading test and a surface abrasion test. The test diagrams are shown in Figures 5 and 6.

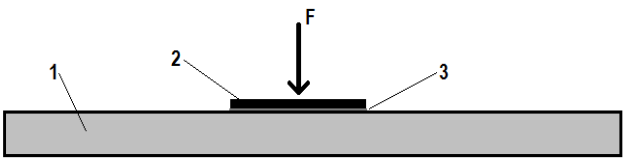

Fig. 5. Diagram of loading test on polymer concrete panel: 1 – polymer concrete panel, 2 – rigid steel slab distributing load on suitable surface, 3 – rubber pad

Rys. 5. Schemat próby nacisku na płytę polimerobetonu: 1 – płyta polimerobetonu, 2 – sztywna płyta stalowa rozkładająca obciążenie na odpowiednią powierzchnię, 3 – podkładka gumowa

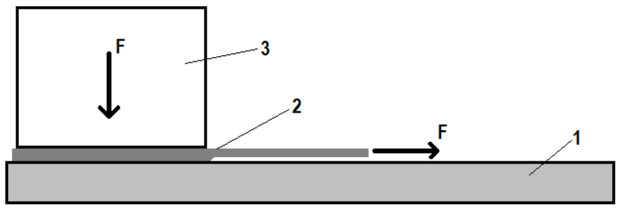

Fig. 6. Diagram of abrasion test of polymer concrete panel surface: 1 – polymer concrete panel, 2 – rubber pad with tongue to enable pulling, 3 – weight

Rys. 6. Schemat próby ścierania nawierzchni płyty polimerobetonu: 1 – płyta polimerobetonu, 2 – gumowa podkładka z wypustem umożliwiającym ciągnięcie, 3 – obciążnik

In the loading test, the load of polymer concrete with the weight of a person standing on it was imitated. For this purpose, a mass of 130 kg was provided, which was placed on a rigid steel plate with an area of 210 cm^2, under which a 1 cm thick rubber pad was additionally placed (imitation of a shoe sole). The unit pressure was approx. 6.2 N/cm^2. After the weight was placed, about 15 seconds passed and the weight was removed. The test was repeated three times in the same sample area.

The abrasion test of the polymer concrete surface was intended to imitate possible sliding related to the movement of objects on the surface or sliding of people. It consisted in placing a mass of 16.2 kg on a rubber pad with a contact surface of 450 cm^2 (unit pressure 0.36 N/cm^2). The pad had a tongue that allowed the pad to be pulled over the surface. The pulling was carried out manually, at a speed of about 10 cm/s, over a distance of 40 cm. The test was repeated three times on the same areas of the sample.

Visual inspection of the samples after the mechanical tests was adopted as the main evaluation method. Additionally, the behavior of the samples during the tests was assessed (e.g. the occurrence of sounds proving detachment of the surface elements).

During the visual inspection of both sample 1 and sample 2, no surface damage effects were observed after the loading tests. Regarding the condition of the surface after the abrasion tests, in the case of sample 2 (gravel aggregate), several individual gravel grains were detached after the first pass. After the second and third passes, no detached particles were observed. In the case of sample 1 (sand-gravel aggregate), no particles broke even on the first pass. On the other hand, in the case of sample 1 a louder shuffling effect of the pad against the surface was found and the need to use more force than in the case of sample 2. This is probably due to the greater smoothness of the surface of the individual gravel particles. The acoustic effect may result from the friction of fine grains of sand, which were not observed with the naked eye during the inspection, against the surface sand.

The second stage of the preliminary utility evaluation of the manufactured polymer concrete panels was tests to assess water tightness and permeability. The tests consisted in controlled pouring of 100 cm^3 of water onto the dry panel surface and observing its spread and absorption by the material, as well as the way and intensity of water leaving the sample.

As expected, sample 1 (containing sand and gravel as aggregate) turned out to be tight. The water flowed smoothly on its surface, with a tendency to run out (a rather hydrophobic surface). A much more significant run-off of water took place along the formed gutter (Fig. 7a). Any water retention on the surface took place only in areas of imperfect leveling of the surface. This result indicates that in the case of professional preparation of a flat surface with an appropriate slope, no significant water retention or absorption by the material should take place.

The behavior of sample 2 was completely different. The lack of the sealing sand fraction resulted in immediate absorption of water by the material, but also its almost immediate flow out from the edge of the lower part of the base layer (Fig. 7b). It proves incomplete filling of the polymer concrete volume (against the theoretical assumptions). The resin does not seal the cavities between the gravel particles, but rather coats them. Between the particles there is a system of interconnected channels, a typical open porosity.

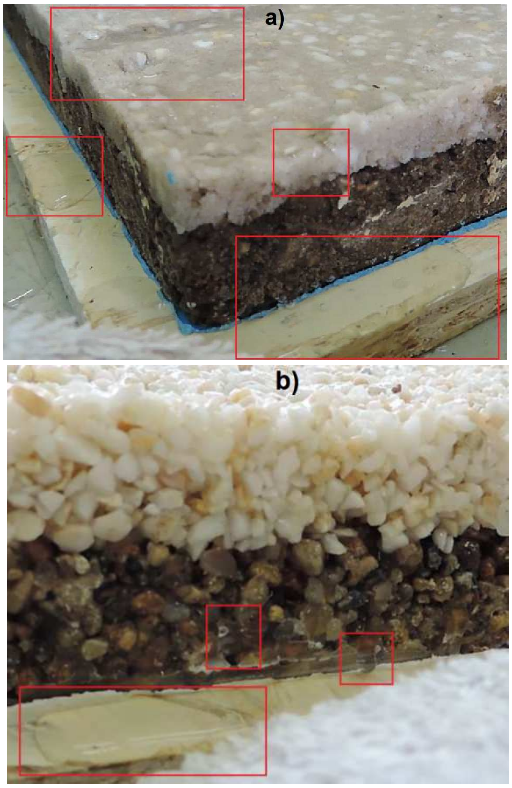

Fig. 7. Tests of interaction of produced polymer concrete panels with water: a) sample 1 with gravel-sand aggregate, visible water running down edges, mainly in area of formed gutter, b) sample 2 with gravel aggregate, visible outflow of absorbed water by side edge of slab

Rys. 7. Próba interakcji wytworzonych płyt polimerobetonowych z wodą: a) próbka 1 o kruszywie żwirowo-piaskowym, widoczne spływanie wody po krawędziach, głównie w obszarze uformowanej rynienki, b) próbka 2 o kruszywie żwirowym, widoczne wypływy wchłoniętej wody przez boczną krawędź płyty

On the one hand, water uptake of an exterior terrace material is disadvantageous as it risks breaking the structure in winter due to bursting caused by freezing. However, the rapid discharge of water indicates the large width of the channels creating the porosity – just for the gravel granulation used.

Taking into account the above results of the assessment of the effect of water on the produced samples, two alternative concepts should be considered when designing a commercial polymer concrete material for terraces. The first one involves precise sealing of the polymer concrete by adding a fine-grained fraction (which has a negative effect on the aesthetics), preventing water from penetrating the structure. The second option, related to the desire to use only gravel aggregate – due to favorable aesthetics, requires the selection of a sufficiently large aggregate (e.g. the 2÷8 mm gravel grain used in the work seems good). It must guarantee large enough porosity channel diameters that they perfectly drain water from the structure, and even if it is absorbed, they provide enough space that any volume increase after freezing can be accommodated. It should also be remembered that open porosity can become clogged with all kinds of dirt. Appropriately large diameters of porosity channels may, however, result in their susceptibility to easily rinse dirt, and even a kind of "self-cleaning", e.g. during intense rainfall. Moreover, if it is not possible to clean it, the dirt clogging the channels can lead to overall sealing of the material as is, for example, in the case of joints between cobblestones. The issue of water absorption does not have to be considered as a factor eliminating the use of gravel polymer concrete in outdoor terraces.

The next tests that were carried out on the produced polymer concrete samples were tests of the susceptibility to dirt and staining. The first tests were to prepare a dirty mass, which was a mixture of sand and dirt swept up in the room (mainly dust settled on horizontal surfaces), dispersed in a small amount of water to the consistency of a paste. The prepared soiling mass was applied to designated areas of the surface of the samples, in a similar measured amount. After waiting for 1 day, the dried dirt was removed from the surface in a repeatable manner from both samples with a dry brush. The effects can be compared in Figure 8.

As can be seen, the dirt was removed with a dry brush from the surface of sample 1 (the gravel-sand aggregate) without any major difficulties and without residue (except for a slight brown non-permanent discoloration) – Figure 8b. The surface of sample 2 (the gravel aggregate) looks much worse, where the dirt has clearly penetrated into the pores and cannot be removed with a dry brush (Fig. 8d).

An analogous portion of the dried dirt, applied as described above, was removed with a brush with water and a popular detergent. The effect is shown in Figure 9.

Sample 1 showed complete removal of dirt from the surface, sample 2 is in the condition similar to cleaning with a dry brush. In summary, the issue of removing dirt is simple in the case of the polymer concrete with sand-containing aggregate, but it is a serious problem for the polymer concrete with the gravel aggregate and high porosity of the surface area.

Due to the fact that the produced polymer concrete is not very susceptible to cleaning from dirt, it was decided to try an additional modifying solution, namely to cover a fragment of the surface with a protective coating. The coating (one type for both samples) was based on epoxy resin – LH288. As for the top layers in the manufactured samples, a mineral coloring component (yellow) 10% by weight, especially for epoxy resins, was added to it. After mixing the resin, the hardener and the mineral component, the resulting mixture was efficiently applied to selected areas of the surface of the samples – Figure 10.

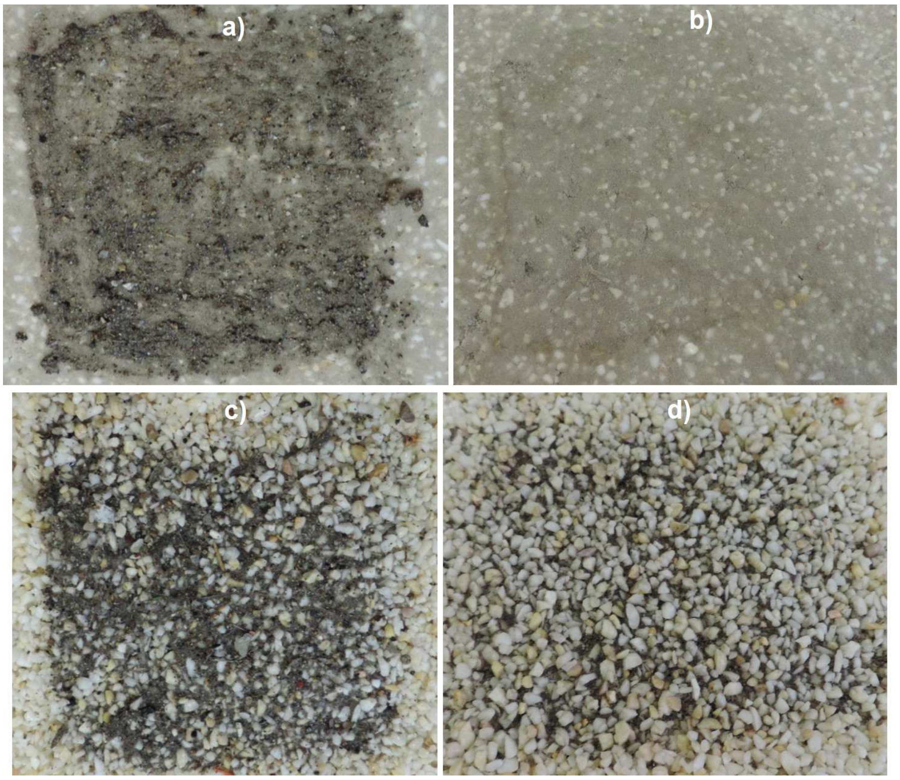

Fig. 8. Assessment of polymer concrete susceptibility to dirt and staining: a) portion of dirt applied to surface of sample 1, b) surface of sample 1 after cleaning dirt with dry brush, c) portion of dirt applied to surface of sample 2, d) surface of sample 2 after cleaning dirt with dry brush

Rys. 8. Ocena podatności polimerobetonu na zabrudzenie: a) porcja brudu naniesiona na powierzchnię próbki 1, b) powierzchnia próbki 1 po oczyszczeniu brudu szczotką na sucho, c) porcja brudu naniesiona na powierzchnię próbki 2, d) powierzchnia próbki 2 po oczyszczeniu brudu szczotką na sucho

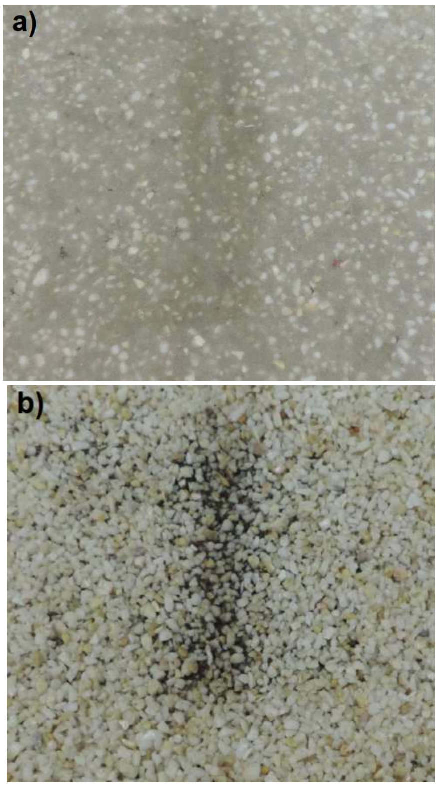

Fig. 9. Assessment of polymer concrete susceptibility to dirt and staining – sample surfaces after cleaning with water with detergent: a) sample 1 surface, b) sample 2 surface

Rys. 9. Ocena podatności polimerobetonu na zabrudzenie – powierzchnie próbek po czyszczeniu wodą detergentem: a) powierzchnia próbki 1, b) powierzchnia próbki 2

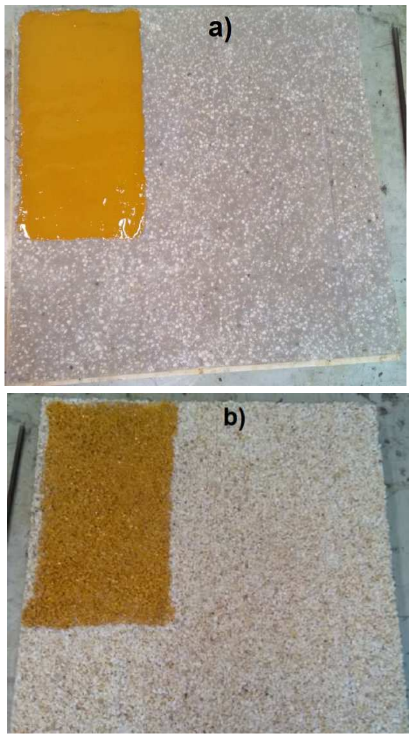

Fig. 10. Coating layers applied to samples 1 (a) and 2 (b)

Rys. 10. Warstwy powłoki osłonowej nałożone na próbki 1 (a) oraz 2 (b)

After the cover layer was applied, it was allowed to cure and left for 5 days in open air in a closed room. Then, on the covered areas of the samples, mechanical tests were carried out - analogically to the previously uncovered surfaces (Figs. 5 and 6). The surface of the coating did not show any damage from the applied loading and abrasion. Thereafter, the coated areas were covered with the prepared dirt paste and allowed to dry (like in the non-covered samples – Figs. 8 and 9). Brush cleaning was performed both dry, and wet with water and detergent. The effects can be assessed in Figure 11.

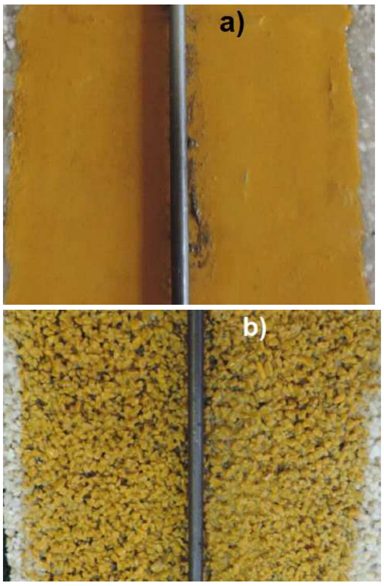

Fig. 11. Layers of resin-based cover coat on polymer concrete samples after cleaning from dirt with brush, dry (left side) and wet with detergent (right side): a) sample 1, b) sample 2

Rys. 11. Warstwy powłoki osłonowej polimerobetonów po czyszczeniu z brudu szczotką na sucho (lewa strona) oraz na mokro z detergentem (prawa strona): a) próbka 1, b) próbka 2

After evaluating the cleaned surfaces of the coatings, it was found that its use improves the removability of dirt in both types of polymer concrete. In the case of sample 2 (gravel aggregate), some residual dirt was found after the wet cleaning. Nevertheless, it is clearly smaller than for the sample without the coating. A sample with a high surface porosity, after being covered with a resin cover layer, is probably fit for use – especially with more careful cleaning. As part of the work, low-intensity cleaning was used, with a similar intensity and time for both samples, in order to be able to make an objective comparison. More intensive cleaning combined with rinsing the surface should ensure complete removal of the dirt, also from the gravel-filled polymer concrete.

ECONOMIC EVALUATION

The estimated gross cost of the materials needed to build a terrace with an area of 15 m^2, according to the concept presented in this study, is respectively: PLN 5470 for the concrete with the gravel-sand aggregate (sample 1) and PLN 4570 for the concrete with the gravel aggregate (sample 2). Note that the most costly component (74 and 88% respectively) is the resin. The calculated value means that the cost of materials for a polymer concrete terrace is comparable to the cost of traditional materials needed for the construction of terraces – such as wood or boards made of thermoplastic composite. In such a case, for mid-priced options, the cost is approximately PLN 4500÷5000. Therefore, it can be said with certainty that polymer concrete is a competitive material. It is not easy to estimate the labor costs, including the preparation of the substrate, when making a polymer concrete terrace. It can be assumed that a 7 cm thick polymer concrete plate (analogous to the one produced in this study) can be placed on unpaved ground, requiring only appropriate leveling and compacting. For a traditional terrace made of boards, or stone or ceramic tiles, 15 m^2 in area, the total labor cost is approximately PLN 7000. It does not seem that the cost of preparing the components, the cost of delivering the components and preparing the polymer concrete mass, as well as the cost of pouring it, would be all higher than the above amount. It can be assumed that for a similar surface, the labor costs for traditional and polymer concrete terraces will be comparable. Therefore, polymer concrete is an interesting competitive alternative that can enrich the market of outdoor terrace surfaces. The above conclusion shows that further research on polymer concrete for outdoor terrace applications makes sense.

CONCLUSIONS

The concept of using a two-layer polymer concrete system as an external terrace surface is good. Based on the preliminary assessment performed, the following conclusions can be drawn:

- The material shows satisfactory behavior in terms of both static and frictional loading and water outflow.
- Polymer concrete with a coarse-grained aggregate is visually attractive after application, but also susceptible to dirt, which is difficult to remove by simple methods. Therefore, it may be difficult to keep clean and aesthetically pleasing.
- Polymer concrete with aggregate containing a fine fraction is easier to keep clean and aesthetic, but is not as visually attractive as that filled only with coarse grained aggregate.
- The applied additional resin protective coating significantly improves the effectiveness of removing dirt from the polymer concrete surface. However, for a coarse-grained surface, the improvement in cleaning performance may occur insufficient.
- According to the applied two-layer concept, polymer concrete is an attractive and real alternative material for outdoor terraces. Nonetheless, the potential proposal of a two-layer polymer concrete as a terrace surface requires a number of further development works, mainly in terms of optimizing the aesthetics and cleanability. Another problem to analyze is the issue of water absorption and freezing inside the polymer

concrete structure, especially when a fine-grained fraction is not included in the aggregate. The economic competitiveness indicates that such work is purposeful.

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REFERENCES

[1] Hop T., Betony polimerowe, Tom I i II, Wydawnictwo Politechniki Śląskiej, Gliwice 1992.

[2] Kozioł M., Łuczak K., Hyla I., Wpływ rodzaju kruszywa i środowiska korozyjnego na zmianę własności polimerowych kompozytów ziarnistych, Materiały Konferencyjne XXXI Szkoła Inżynierii Materiałowej, Kraków, Krynica 2003.

[3] https://www.archdaily.com/catalog/us/products/14037/polymer-concrete-facade-unielectrica-ulma-architectural-solutions (access 03.09.2020).

[4] http://www.inzynierbudownictwa.pl/technika,materialy_i_technologie,artykul,betony_polimerowe_stosowane_w_budownictwie,9353 (access 03.09.2020).

[5] https://www.liniowe-odwodnienia.pl/pl/Nasza-oferta/Odwodnienia-liniowe-polimerobetonowe (access 03.09.2020).

[6] https://www.hobas.com/pl/technology/ (access 29.11.2019).

[7] David W., Fowler D.W., Meyer A.H., Paul D.R., Polymer Concrete for Pavement Repair and Rehabilitation, project report (No. 3-18-79-246), Center for Transportation Research, University of Texas, Austin 1983.

[8] Sorrentino L., Bellini C., Polini W., Turchetta S., Performance index of natural stones-GFRP hybrid structures, Frattura ed Integrita Strutturale 2018, 46, 285-294.

[9] Pappu A., Thakur V.K., Patidar R., Asolekar S.R., Saxena M., Recycling marble wastes and Jarosite wastes into sustainable hybrid composite materials and validation through Response Surface Methodology, Journal of Cleaner Production 2019, 240, article UNSP. 118249, DOI: 10.1016/j.jclepro.2019.118249

[10] Bursa J., Pomianowski J., Żywice epoksydowe modyfikowane wypełniaczami krzemianowymi, Przegląd Elektrotechniczny 2014, 90, 3, 219-222.

[11] Oliwa R., Bulanda K., Oleksy M., Ostynska P., Budzik G., Plocinska M., Krauze S., Fire resistance and mechanical properties of powder-epoxy composites reinforced with recycled glass fiber laminate, Polimery 2020, 65, 4, 280-288.

[12] Kozioł M., Nasycanie ciśnieniowo-próżniowe zszywanych oraz tkanych trójwymiarowo preform z włókna szklanego, monografia, Wydawnictwo Politechniki Śląskiej, Gliwice 2016.

[13] Chatys R., Piernik K., Influence of scale effect and time on strength properties of polymer composite made by vacuum method, Composites Theory and Practice 2018, 18, 2, 103-109.

[14] Hajduk P., Projektowanie i ocena techniczna betonowych podłóg przemysłowych, WN PWN, Warszawa 2018.

[15] Lv Z., Li B., Li L., Ma W., Application of Polymeric Cement Concrete as Overlay Material on Old Concrete Pavements for Low Volume Roads: Chinese Experience, Proceedings of Fourth Geo-China International Conference, Shandong, China, July 25-27, 2016.

[16] http://tdmtarasy.pl/taras-drewniany-czy-kompozytowy-wady-zalety/ (access 03.09.2020).

[17] https://receptynadom.pl/zrobic-betonowy-taras-stykajacy-sie-domem/ (access 03.09.2020).

[18] https://gambrick.com/problems-with-trex-decking/ (access 23.08.2020).

[19] https://us.kebony.com/blog/composite-decking-the-best-alternative-to-composite-decking-boards/ (access 23.08.2020).

[20] Aleksendric D., Bellini C., Carlone P., Cirovic V., Rubino F., Sorrentino L., Neural-fuzzy optimization of thick composites curing process, Materials and Manufacturing Processes 2019, 34, 3, 262-273, DOI: 10.1080/10426914.2018.1512116.

[21] Jesionek M., Toroń B., Szperlich P., Biniaś W., Biniaś D., Rabiej S., Starczewska A., Nowak M., Kępińska M., Dec J., Fabrication of a new PVDF/SbSI nanowire composite for smart wearable textile, Polymer 2019, 180, 121729.

[22] Boczkowska A., Chabera P., Dolata A.J., Dyzia M., Kozera R., Ozieblo A., Fabrication of ceramic-metal composites with percolation of phases using GPI, In: Light Metals and Their Alloys II: Technology, Microstructure and Properties, Eds. A.J. Dolata, M. Dyzia, Book Series: Solid State Phenomena 2012, 191, 57-66, DOI: 10.4028/www.scientific.net/SSP.191.57.

[23] Szperlich P., Nowak M., Jesionek M., Starczewska A., Mistewicz K., Szala J., Desorption of gasses induced by ferroelectric transition in SbSI nanowires, Acta Physica Polonica A 2014, 126, 1110-1112.

[24] Mistewicz K., Recent advances in ferroelectric nanosensors: toward sensitive detection of gas, mechanothermal signals, and radiation, Journal of Nanomaterials 2018, 1-15, Article ID 2651056, DOI: 10.1155/2018/2651056.

