***Shutenko L.**, doctor of science, professor*
***Zolotov M.**, candidate of science, professor*
***Zolotov S.**, candidate of science*
Kharkiv National Academy of Municipal Economy
Ukraine

Compositions on the basis of acrylic polymers for repairing cement-concrete pavements and reinforced concrete bridge structures

Application of materials with high strength based on polymeric binding materials for repairing cement –concrete pavements and reinforced concrete bridge structures is considered to be one of the ways of increasing strength and durability of these constructions. Compositions based on acrylic polymer were worked out by the authors for these purposes.

These compositions consist of an acrylic compound and a filling (quartz sand). It has been found experimentally that acrylic compositions are characterized by high mechanic strength: 46-92 MPa at pressure, 16-41 MPa at bending, 18-28 MPa at tension and 21-30 MPa at cutting. It has been also found that acrylic compounds possess high adhesive properties. The strength of glue compounds based on acrylic compositions is determined by concrete strength.

It has been found that acrylic polymeric compositions possess low and regulated viscosity and sufficient viability. Time necessary for their hardening ranges from 4 to 24 hours and depends on a series of factors, including surrounding temperature.

Application of materials with high strength based on polymeric binding materials for repairing cement-concrete pavements and reinforced concrete bridge structures is considered to be one of the ways of increasing strength and durability of these constructions. Compositions based on acrylic polymer were worked out by the authors for these purposes [1-8]. The composition includes acrylic compound consisting of polymeric powder and liquid-like hardener and a filling (quartz sand).

Powdery component is a high-molecular substance being a suspension polymer on the basis of polymeric methyl and acryl. 1% of benzoil is included into polymerization process of a powder.

Liquid-like component of the composition is methyl ether of methacryl acid in which 3% of dimethylanilin are dissolved and is known to be a hardener.

Hardening of acrylic composition is carried out at positive temperature due to polymerization based on the reaction of oxidizing and restoring systems. Benzoil in powder is considered to be an oxidizer and dimethylanilin in liquid of methylmethacrylate is considered to be a restorer.

As compound components are produced at a plant acrylic composition consists of few components. It is simple and reliable in production, not very expensive and has high technological properties [1, 2, 6, 7].

The aim of this work is to show how physical and mechanic (cohesive and adhesive strength, elasticity module Ek) and technological (toughness, liability, hardening time) properties change under the influence of different factors: compound content, amount and size of filling grains. These data are expected to allow operating the use of acrylic compositions depending on the purpose.

Cohesive strength of acrylic compositions is determined by testing experimental samples using short-term static loading at tension, pressure, bending and shear. Experimental samples were produced by means of pouring acrylic composition into steel moulds. They were tested for composition polymerization in three days. Quartz sand with grains of different size (0.14, 0.315, 0.63 mm and Volskiy sand) was used as a filling.

Short-term strength determination for pressure was carried out using samples in the form of a cube with a rib equal to 40 mm, testing for tension was carried out using eight-form samples with the length of a working part equal to 60 mm and with cross section 10x20 mm, at bending – using samples in the form of a beam with the length 120 mm and cross section 10x15 mm; at shear – using samples in the form of a prism with the size 50x50x25 mm.

Composition elasticity module was calculated on the basis of measured longitudinal and cross deformation at tension level not exceeding 0.3 Rpress, where Rpress – the strength of acrylic composition at pressure.

Deformation was determined using prisms 40x40x16mm. The method of electrotensometry was used in the process of measurement. For this purpose 4 tensoresistors were stuck to each rib of a sample lengthwise and perpendicular to loading line. After centralizing the samples were loaded in steps of 0.1Rpress along physical axis up to destruction. At each stage of loading the quantity of longitudinal and cross deformation has been noted.

Influence of a filling amount on acrylic composition strength and the relation between polymer and a hardener in a compound have been experimentally found.

The results obtained proved the following. On trials fragile destruction of acrylic composition samples has been observed. It has been also shown in diagrams of compositions deformation at pressure.

The analysis of the data obtained showed that acrylic compositions strength depended on the amount of a filling and a hardener in them and on the size of quartz sand grains.

So, acrylic composition strength at pressure decreased from 90.6 to 46.4 MPa, at cutting – from 29.8 to 21.2 MPa, at bending – from 40.8 to 26.2 MPa and at tension – from 18.5 to 12.7 MPa, at the increase of quartz sand amount (the size of grains is equal to 0.14 mm) – from 150 to 400 m.-p.

A filling (quartz sand) grains size change also causes the change of acrylic composition strength. So, introduction of 200 m.-p. of quartz sand with grain size 0.14, 0.315 and 0.63 mm into the composition caused the increase of strength limit for pressure from 66.9 to 95.4 MPa. At the same time the change of composition strength limits at cutting, bending and tension from 28.0 to 24.8 MPa, from 31.6 to 23.5 MPa and from 17.3 to 13.7 MPa has been observed.

The increase of a hardener amount from 100 to 200 m.-p. causes the decrease of acrylic composition strength at pressure from 80.2 to 66.9 MPa, at cutting – from 29.1 to 28.0 MPa, at bending – from 36.6 to 31.7 MPa.

The experiments revealed that acrylic composition elasticity module Ek depended on the amount of a filling in it greatly. It can change from $36x10^3$ to $12x10^3$ MPa. In the first case there were 100 mass.-p. of quartz sand with grains 0.14 mm in a filling and in the second – 700 mass.-p. of sand with grains 0.63 mm.

The adhesive strength of acrylic composition was determined by testing at uniform tearing off metal punches welded to concrete Ptear; uniform tearing off two metal washers from each other; glue combinations of concrete samples for shear.

In the first case metal washers with the diameter 50 mm stuck to the surface of concrete samples with acrylic composition were tested using uniform tearing off according to the scheme presented in fig.1.

Testing was carried out on concrete cubes with the square of cross section 100x100 mm. The cubes were made of class B15 concrete. Concrete surface was prepared by scaling a cement layer to visual embedment of crushed stone.

Metal punch skimmed by acetone was stuck to concrete with acrylic composition. Samples were tested using tearing machine. The value of composition adhesion to concrete was calculated as relation of force spent on tearing off a punch to its square: $R_{tear} = P_{tear} / F_{punch}$

Beams were stuck by acrylic composition. Glue layer thickbness was equal to h_{stick} = 2mm, stick square F_{stick} = 60 cm^2. Testing of all samples was carried out after three days of composition hardening at surrounding temperature 20 ± 2ºC.

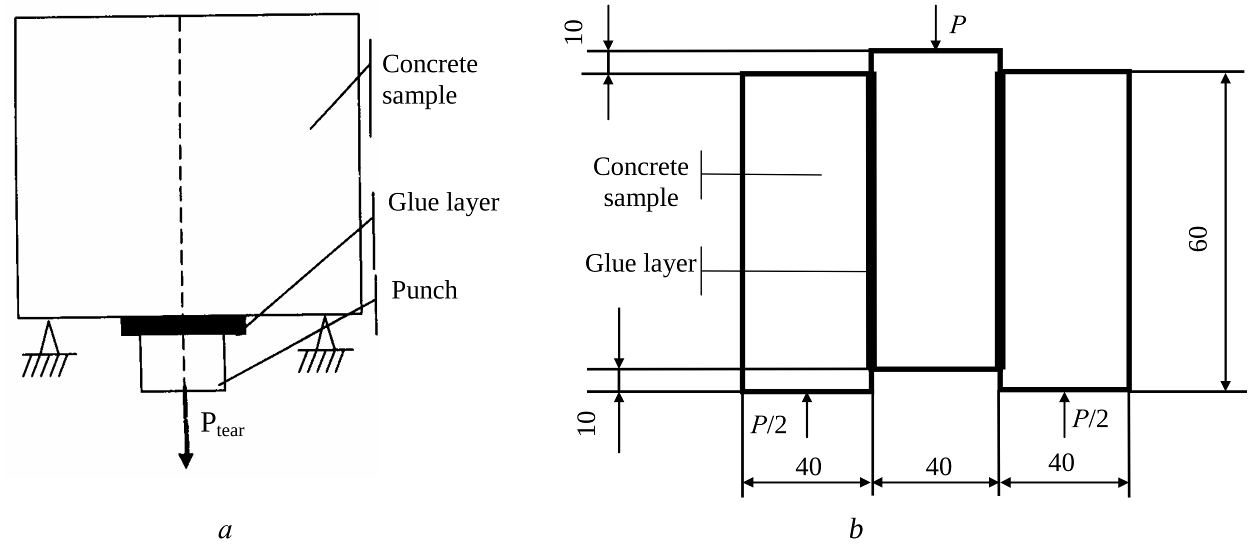


Fig. 1. Testing schemes of glue combinations for tearing off (*a*) and shear (*b*).

Adhesive strength was calculated by the formula: $R_{shear}= P_{destr} / (2F_{tear})$, where P_{destr} - destructive force.

Testing of all glue combinations samples was carried out after three days of acrylic composition hardening.

Experimental results are the following.

Metal-concrete combination strength. The results of investigating adhesive strength of composition combinations samples in case of tearing off metal washers stuck to concrete by mentioned above composition showed that the strength of such combinations is determined by concrete strength. In all cases destruction of the combination metal-concrete occurred on concrete. It speaks of high adhesion of acrylic compositions of all investigated contents to concrete.

Concrete-concrete combination strength. The results of investigating adhesive strength of glue combinations concrete-concrete for shear showed the following: introduction of different admixtures into acrylic composition doesn't influence the change of combinations strength. The strength of these combinations is determined by concrete strength, because in all cases of testing destruction occurred on concrete. It speaks for the fact that adhesive strength of different acrylic compositions exceeds cohesive strength of concrete.

The data obtained make us come to the conclusion that acrylic compositions can be applied for repairing and restoration of cement-concrete pavements and reinforced concrete bridge structures.

One of the most important technological indices of any polymeric composition is toughness. Determination of dependence of composition toughness on a series of factors is considered to be important for working out the technology of repairing and restoration of cement-concrete pavements and reinforced concrete bridge structures.

As the composition consists of acrylic compound and a filling, investigation of polymer solution production has been carried out. It showed that the use of natural quartz sand with grains size from 0.14 to 0.63 mm as a filling was more expedient and environmentally friendly.

The following formula of composition production has been experimentally determined. Polymer is introduced into a hardener at continuous mixing. After mixing, polymer swelled to consistence excepting its settlement. The end of swelling resulted in obtaining one-color sticky mass with relative toughness 38…40 cm on Suttard viscosimeter. Then, during continuous mixing, necessary amount of quartz sand was introduced.

It has been also found that optimum compound toughness for filling it with quartz sand on Suttard viscosimeter is equal to dim diameter 38…40 cm, and maximum – 24 cm.

It has been experimentally determined that to be applied for repairing acrylic compositions are to possess maximum toughness 35 cm (mass dim diameter on Suttard viscosimeter), optimum – 24 cm and retain sufficient fluidity till gaining toughness equal to 16 cm. With the dim diameter 13…15 cm composition can be hardly laid and with the diameter 12 cm it loses its fluidity. With composition dim diameter 10 cm and less it also loses its adhesive strength.

Depending on the composition content the influence of a hardener amount on its toughness has been determined. The amount of a filling was the same in this experiment. The results are presented in fig.2.

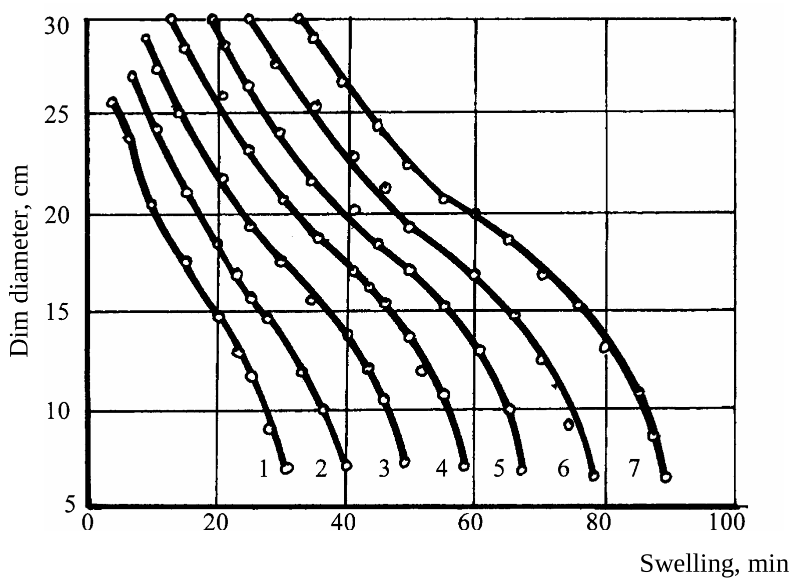


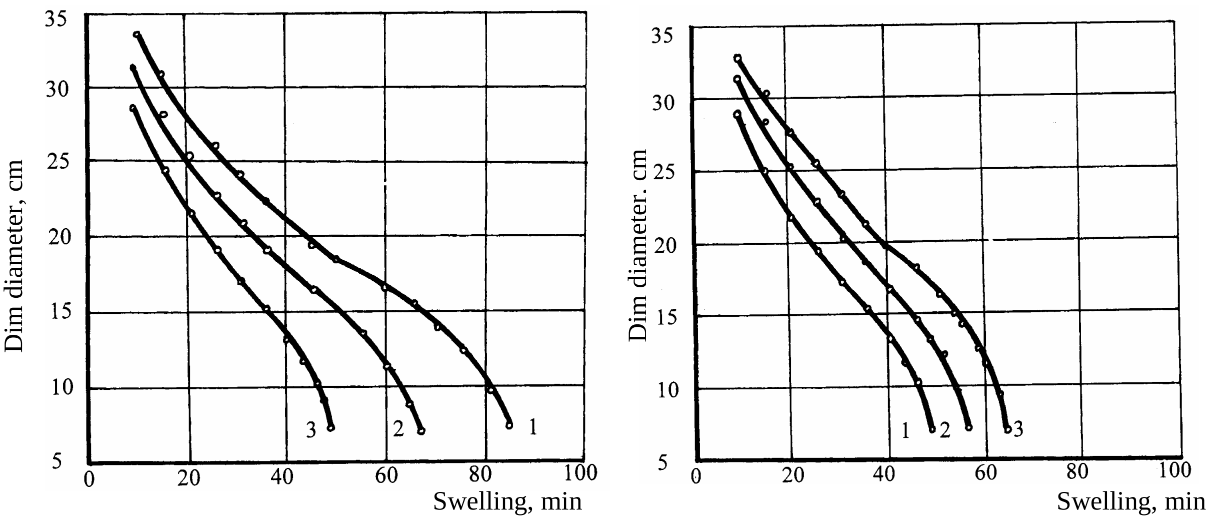
Fig.2. Influence of hardener on composition toughness. Hardener, mass.-p.:
1 – 60, 2 – 80, 3 – 100, 4 – 120, 5 – 140, 6 – 160, 7 - 180.

The results of the experiments for determination of an amount and size of a filling on composition toughness are presented in fig.3. In the first case (fig.3, *a*) quartz sand with grains 0.14 mm (50, 100, and 150 mass.-p.) were used as a filling, in the second (fig.3, *b*) – 0.14, 0.315 and 0.63 (150mass.-p.).

The analysis of the data speaks for the fact that with the increase of a filling amount composition toughness increases and with the increase of grains size toughness decreases. It can be explained by the influence of highly developed surface of quartz sand grains, its orientating ability when structuring a composition. These indices testify to the role of a filling as a structuring admixture.

The experiments for determination of the influence of surrounding temperature on acrylic compositions toughness were carried out at 0, 5, 10, 15, 20 and 25 ºC. They showed that the surrounding temperature didn’t influence toughness. It remained unchangeable at different temperature.

When using acrylic composition for repairing cement-concrete pavements and reinforced concrete structures, the extent of filling a compound with quartz sand of different size is considered to be an important factor influencing the value of its toughness. Knowing this factor allows extending a choice of optimum compositions and determining the possibility of using highly filled acrylic compositions with sufficient mobility.



a *b*

Fig.3. Influence of a filling amount (*a*) and its grains size (*b*) on acrylic composition toughness:
a – quartz sand, mass.-p.: 1 – 50, 2 – 100, 3 – 150;
b – grains size: 1 – 0.14 mm, 2 – 0.315 mm, 3 – 0.63 mm.

The influence of sand grains size on filling of the main acrylic compound has been investigated using quartz sand (with grains 0.14, 0.315 and 0.63 mm) and Volskiy sand. For determining the influence of compound the amount of a hardener was changed from 60 to 200 mass.-p. for 100 mass.-p. of polymer. Quartz sand with grains 0.14 mm was taken in this case. The results of the investigation are given in fig.4 and 5.

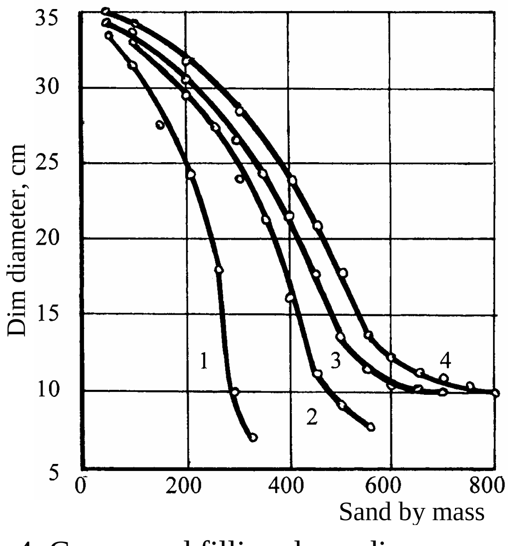


Fig.4. Compound filling depending on sand grains size. grains: 1 – 0.14 mm, 2 – 0.315 mm, 3 – Volskiy sand, 4 – 0.63 mm.

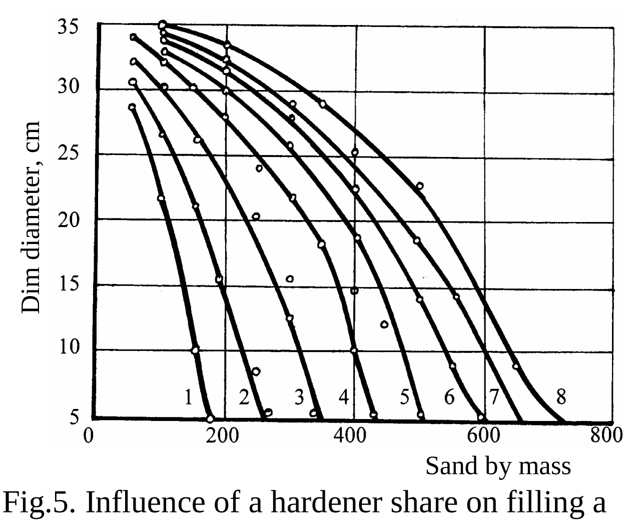


Fig.5. Influence of a hardener share on filling a compound with sand with grains 0.14 mm. Hardener, mass.-p.: 1 – 60; 2 – 80; 3 – 100; 4 – 120; 5 – 140; 6 – 160; 7 – 180; 8 – 200.

The limit of filling acrylic compound equal for sand with grains 0.14 mm – 300, 0.315 mm – 500, 0.63 mm – 800 and Volskiy sand – 700 mass.-p. has been determined.

As can be seen in diagrams in fig.4 and 5, acrylic composition toughness can be regulated by introducing quartz sand with different grains. Composition containing sand with grains 0.14 mm – 180, 0.315 mm – 300, 0.63 mm – 400 and Volskiy – 350 mass.-p. is characterized by good mobility (relative toughness – 0.24 cm). This conclusion conforms with recommended compositions adopted when investigating acrylic composition strength. The increase of a hardener amount to 200 mass.-p. allows increasing the amount of quartz sand with grains 0.14 mm to 700 mass.-p. (fig.5).

So, the influence of different factors on acrylic composition toughness and the possibility of its regulation have been experimentally found.

Viability has been experimentally determined by changing relative toughness of a compound and filled composition on Suttard viscosimeter. Full and technological viability of a compound was determined depending on its content and temperature: full – a period of time from the moment of production to the beginning of hardening; technological – a period of time from the moment of mixing only the components of a bending material to gaining toughness, when the composition becomes unfit for filling with sand. Alongside with determination of relative toughness on Suttard quartz sand was introduced into the vessel with the compound for gaining toughness, excluding filling it with sand.

Technological viability of filled composition – a period of time from the moment of its production to its gaining toughness preventing it from use, was also determined. Alongside with determination of relative toughness on Suttard the investigated composition was poured on the spot for determining this value.

Dependence of composition viability on relation between components was determined at a temperature of 20 ± 2ºC. Dependence of viability on the temperature (0, 10, 15, 20 and 25ºC) was determined using composition (parts by mass) 100:100:150 of polymer, hardener and quartz sand with grains to 0.14 mm.

It has been found that for the use in repairs acrylic composition is to possess minimum relative toughness 35 cm (mass dim diameter on Suttard viscosimeter), optimum – 24 cm and to retain sufficient fluidity to gaining toughness equal to 16 cm. When dim diameter is 13…15 cm composition can be hardly laid on construction and when it is 12 cm composition loses its fluidity. All mentioned above factors have been taken into account when determining technological viability of acrylic composition.

The investigation showed that when monomer content increases from 60 to 180 mass.-p., composition viability increases from 22 to 43 min. The main recommended composition content at 20 ºC has technological viability 27 min. When using less sand or increasing its grains it is possible to increase composition viability to 57 min., retaining bearing capacity of repaired construction.

Surrounding temperature (fig.6) is known to influence viability. When the temperature falls, technological viability increases and is equal to 19, 27, 42, 67 and 259 min. at 25, 20, 15, 10 and 0 ºC. This phenomenon fits experimental data of other researchers.

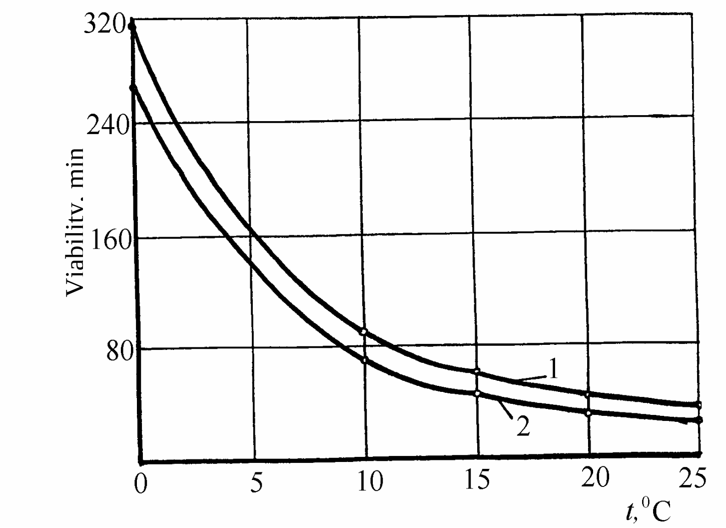


Fig.6. Dependence of composition viability on surrounding temperature.
Viability: 1 – full; 2 – technological

Carried out investigation showed that acrylic composition possessed sufficient viability and by this parameter it can be used for repairing cement-concrete pavements and reinforced concrete bridge structures. Its viability may be regulated by compound content, amount and size of filling grains. Surrounding temperature also influences composition viability.

On the basis of experimental results acrylic compositions content with toughness from 18 to 27 cm on Suttard are recommended for above mentioned repairing works.

Acrylic composition hardening occurs at normal temperature with available two component initiating (oxidative-restoring) system able to cause polymerization of vinyl monomers.

In acrylic composition physical and chemical processes of hardening are accompanied by releasing exothermal heat. For investigating the influence of a filling on the nature of chemical reaction proceeding thermograms of the process of acrylic composition polymerization were taken. Besides, hardening time was determined using acoustic method and by composition strength change at pressure. In the first case time of ultrasound passing and its velocity until measured values become stable were registered using special and ultrasonic devices. At the same time the temperature of mass hardening was measured.

Hardening velocity on the strength increase in time was determined using cube samples with a rib 40 mm, tested for pressure at a temperature of 20 ± 2ºC. The first part was tested immediately after hardening phase, the rest – each hour until gaining stable mass.

Influence on kinetics of composition polymerization, amount and size of a filling, hardener and surrounding temperature were also investigated.

The type of exothermal curves of the process of acrylic composition polymerization with different content speaks of their identity. In the initial stage polymerization process developed slowly. During 20 min. from the moment of exothermal effect appearance the temperature of investigated polymer solution rises to 35-40 ºC. Then, in 1-2 minutes the temperature is 10 ºC higher and during next 3-4 minutes it reaches its maximum (exothermal peak) equal to more than 100 ºC. Later on, uniform fall of composition temperature is observed and it reaches the level of surrounding temperature (in 278-285 min.). In the period of cooling a characteristic point on exothermal curves is 30 ºC, to which all curves irrespective of acrylic composition content, value and time of exothermal peak, approach in time. After that temperature change in all contents occurs in parallel.

Investigation carried out using acoustic method showed that intensive hardening of acrylic composition occurred at the moment of sharp rise of temperature to maximum, it is expressed with almost vertical straight line on the diagram of ultrasound passing velocity through the composition (fig.7). When reaching maximum temperature (exothermal process) composition transforms to solid phase. Later on, the increase of ultrasound passing velocity slows down and by the moment of cooling a composition to the temperature of 30 ºC it is stable. When monomer and quartz sand amount increases or a filling grains size decreases, ultrasound passing velocity increases.

So, the intensity of hardening of investigated composition contents is considered to grow when the content of quartz sand increases and its size decreases, it points to the role of a filling as a structure formation admixture. Hardening period at 20 ºC changes from 75 to 91 min. depending on the content. Carried out investigation, using acoustic method, supports the conclusion that structure formation occurs during first two hours at mentioned temperature. It is substantiated by the change of cohesive strength in time. Strength at pressure was taken as the main index of cohesive strength, investigated for determining the intimacy of acrylic composition polymerization. This parameter was investigated at 23 ± 2ºC depending on the share of monomer in a composition content, amount and fraction of quartz sand.

The analysis of experiments showed that at constant surrounding temperature acrylic composition polymerization velocity changed a little. Its strength reaches optimum values during 24 hours.

Considerable change of polymerization velocity occurs at variations in temperature (fig.7). When the temperature falls from 25 to 10 ºC polymerization reaction 6 times slows down (extreme temperature appears), it is caused by slow formation of active centers and the chain increase.

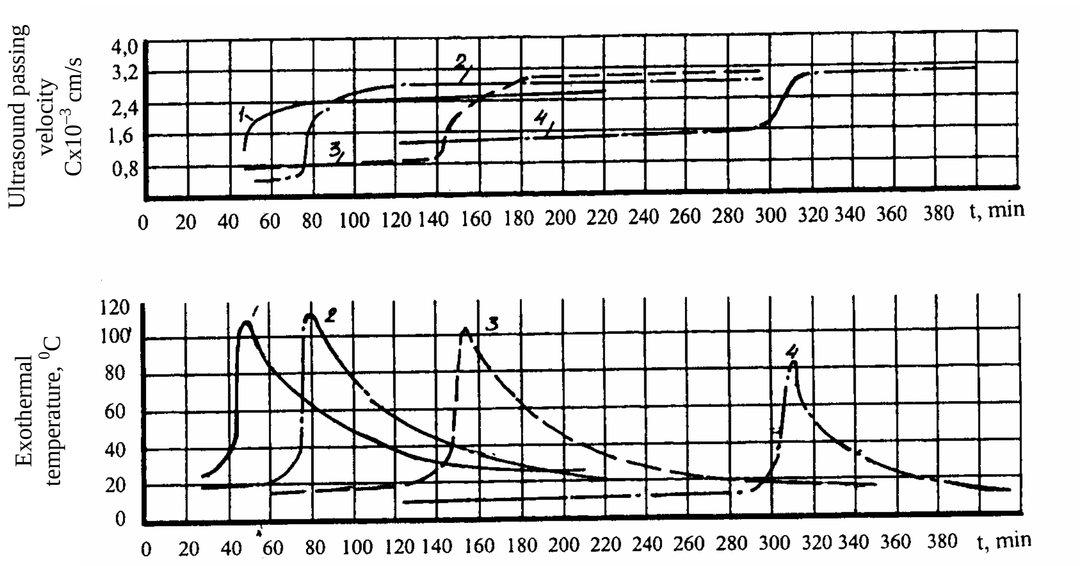


Fig.7.Influence of surrounding temperature on the duration of acrylic composition hardening. Temperature: 1 – 25 ºC, 2 – 20 ºC, 3 – 15 ºC, 4 – 10 ºC.

In general, the investigation shows that intensive structure formation occurs in the period of sharp rise of exothermal temperature – composition transforms into solid phase gaining high strength. Irrespective of the content considerable increase of strength at 20-23 ºC occurs during first 3 hours from the moment of composition production and is equal to 85%, and in 9 hours – 90% of the final strength. When the surrounding temperature falls, polymerization reaction slows down. But the possibility of composition polymerization at a temperature of about 0 ºC without additional un: dertakings was found.

1. Шутенко Л.Н., Золотов М.С., Гарбуз А.О. Ресурсосберегающий модифицированный акриловый клей с повышенной адгезионной прочностью и теплостойкостью // Ресурсоекономні матеріали, конструкції, будівлі та споруди: Зб. наук. праць. Вип. 3. – Рівне: РДТУ, 1999. – С.57-63.

2. Шутенко Л.Н., Золотов С.М., Гарбуз А.О. и др. Использование акриловых композиций для реконструкции и ремонта зданий и сооружений // Будівельні конструкції: Зб. Наук. праць. Вип.54. – К.:НДІБК, 2000. – С. 810-814.

3. Патент №49650. Україна. МКИ С09J4/00, СО8L33/12. Композиція для кріплення анкерних болтів у бетоні / Шутенко Л.М., Золотов С.М., Волювач С.В., Золотов М.С. – № 2002010074; Заявл. 03.01.2002. Опубл. 16.09.2002.

4. Zolotov S. Adhesive on the Basis of Acrylic Compound to Join Concrete and Reinforced Concrete Elements // Science, Education and Society: 11 International Scientific Conference University of Zilina. Slovak Republic, part I, 2003. – P. 323-325.

5. Патент № 70656А. Україна. МКИ СО9J4/02, СО8L33/12. Полімерна самотвердіюча композиція / Шутенко Л.М., Золотов С.М., Гарбуз А.О., Золотов М.С. – № 2007105734. Заявл. 10.10.2003. Опубл. 15.10.2004.

6. Золотов С.М. Инновационные материалы на основе акриловых полимеров для восстановления и ремонта конструкций объектов строительства и транспорта // Инновационные технологии диагностики, ремонта и восстановления объектов строительства и транспорта: Сб. науч. тр. Вып. 30. – Днепропетровск: ПГАСА, 2004. – С. 192-196.

7. Золотов С.М. Акриловые клеи для крепления анкерами башенных сооружений // Будівельні конструкції, будівлі та споруди: Зб. наук. праць. Вип.5. – Макіївка: ДонДАБА, 2001.– С.179-182.

8. Zolotov S. Strength and deformation of acrylic Glues under temporary and permanent static loading // Proceedings of the 3rd International Conference on Dynamics of Civil Engineering and Transport Structures and Wind Engineering. – Slovak Republic, Zilina, 2005. – P. 123-126.