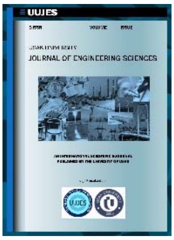

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Research article

THE EFFECT OF POZZOLANIC MATERIAL AND WASTE FOUNDRY SAND ON FRESH MORTAR PROPERTIES AND PREDICTION OF SOME RESULTS BY ARTIFICIAL NEURAL NETWORKS

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Abstract

Waste reuse is frequently included in scientific studies. As a result of the increase in production after the Industrial Revolution, this waste is increasing day by day. One of these wastes is waste casting sand used as molding sand in the casting industry. In this study, the effects of this waste and silica fume and fly ash, which are also waste materials, on fresh mortar properties were investigated. Different proportions of fly ash, foundry sand, and silica fume mixtures were used in the study. Spreading tests were carried out on the mixtures with mini v funnel and mini-slump funnel according to EFNARC. According to the experiments, we tried to determine the most suitable mortar mixtures in terms of workability with appropriate material selection. The effect of waste materials on workability has shown a positive development. It tried to determine the test results of some mixtures by modeling with artificial neural networks. The effect of water content in some mixtures was also analyzed, and it was concluded that a 0.3 w/b ratio was the most suitable. The cement dosage was kept constant at 800 kg/m^3, and other variables were analyzed. The substitutions of pozzolanic materials were proportioned over the cement dosage.

Keywords: *Recycling, silica fume, fly ash, mortar workability, waste foundry sand, artificial neural networks.*

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1. Introduction

In today's concrete production, plasticizer is an indispensable material in terms of setting, strength and workability of concrete. It is known that the need for mixing water (>20%) is reduced with the addition of plasticizers. It is also possible to extend the setting time and reduce the hydration temperature by increasing mineral and chemical admixtures [1].

It is known that the substitution of silica fume for cement has a favorable effect on mortar properties in many aspects [2]. These properties include mechanical properties as well as workability [3]. The use of silica fume in mortar provides reductions in water absorption and porosity as well as improvements in compressive strength [4]. Silica fume (SF) is efficacious in improving the rheological properties of concrete. However, it may also cause an adverse effect if the appropriate ratios are exceeded. Silica fume increases the yield stress and plastic viscosity of cement mortar. This is due to the fact that very fine particles in the gel mix require high interaction forces. Filling the gaps between the particles and reducing the gap distances are also the reasons for the difficulty of movement. It is known that the use of fly ash up to 20% contributes to compressive and tensile strengths [5]. The yield stress and plastic viscosity can be reduced by using less than 50% fly ash content. As fly ash fills the voids, the void water turns into free water and increases the fluidity. The use of limestone powder (LSP) increases the yield stress and plastic viscosity. In some studies, it was also stated that these properties change with the fineness of limestone powder. For example, while 15 μm LSP decreased these properties, the viscosity increased up to two times with 0.7 and 0.3 μm LSP [6].

Forecasting with machine learning has been increasingly used in publications in recent years. Modeling with artificial neural networks (ANN) to obtain prediction results has been one of the most popular study methods. The discipline of civil engineering is also being researched in this field [7]. In the study, the compressive strengths of rice husk ash substituted concrete were predicted using ANN modeling, and the experimental results and ANN predictions were predicted with very few differences. According to these results, it was concluded that it is helpful to carry out studies with ANN predictions without using experimental methods [8]. Researchers are investigating the effect of recycled aggregate on the mechanical properties of concrete production modeled with 1030 data sets consisting of literature information. Eight input parameters were cement, blast furnace slag, water, super plasticizer, coarse aggregate, fine aggregate, and concrete age data. According to the results of the research, it was stated that high-accuracy results can be obtained with ANN-based models [9].

Research on the rheological properties of self-compacting concretes (SCC) is still inadequate. In this study, binder, fly ash, water, fine aggregate, coarse aggregate, and superplasticizer data were used as inputs in order to predict the fresh concrete properties of self-compacting concrete with ANN. The output data to be predicted consist of spreading diameter, V-funnel flow time, L-box ratio, and compressive strength in the hard state. When the results are evaluated, it is possible to predict the ANN model accurately according to the input parameters [10]. In order to eliminate human error during experiments, modelling such as ANN is recommended [11].

Waste foundry sand is the material that the molding sand used by the metal industry becomes unusable as a mold. Molding sand is generally made of silica sand (80-95%), clay (bentonite) (4-10%), coal dust (2-10%), water (2-5%) [12]. Bentonite and coal in the waste foundry sand reduce the workability by high water absorption in the concrete mix [13]. In the case of the calcination process, all of the aggregates can be replaced by waste-foundry sand [14].

Foundry sand contains metals that are poured into it during its use in molding. These metals may enter undesirable reactions in concrete. For example, the usability of waste-foundry sands containing lead was investigated with normal Portland cement. According to this research, lead reacted with portlandite ions to produce lead hydroxide. This prolonged the setting time and delayed the hydration reaction [15].
The use of waste foundry sand in concrete is beneficial in terms of greenhouse gas emissions, waste disposal, and sustainability. Research shows that waste caster sand can be used up to 30% as a substitute for fine aggregate [16], [17], [18], [19], [20], [21].

The effect of the use of waste foundry sand on concrete properties was investigated using Multi-Expression Programming [22]. With these modeling methods, experimental waste can be reduced. At the same time, the estimated values on the optimum replacement ratio and strength relationships were found with high regression values [0.98-0.99) compared to the actual experimental results programming [23].

2. Materials

2.1 Limestone Powder

Limestone powder (LSP) is a raw material used for many purposes in cement and concrete. It is processed into coarse and fine aggregates for clinker production. It is produced as limestone dust in quarries and is intended to be used as an additive to Portland cement. While some researchers consider the effect of limestone dust as a filler for cement cavities, others say that this is due to its physical properties [3]. Limestone powder used in the study was obtained from Kolsan Afyonkarahisar production facilities. The aggregate was sieved to a maximum diameter of 600 microns, and the grain distribution is shown in Fig. 1 and Table 1. In order to determine the physical properties of the aggregate, unit volume weight, specific gravity, and water absorption tests were performed, and these properties are given in Table 2.

Table 1. Sieve analysis table of limestone powder

Sieve Aperture [mic]	On The Sieve Remainder (gr)	Cumulative Remaining On The Sieve (gr)	Cumulative Remaining (%)	Cumulative Passing Through The Sieve (%)
600	0	0	0,00	100,00
500	7,8	7,8	0,84	99,16
425	42,6	50,4	5,43	94,57
250	74,8	125,2	13,49	86,51
212	133,9	259,1	27,93	72,07
156	347,1	606,2	65,34	34,66
125	272,2	878,4	94,68	5,32
75	25,6	904	97,43	2,57
63	6,5	910,5	98,14	1,86
T. Kabı	17,3	927,8	100,00	0,00

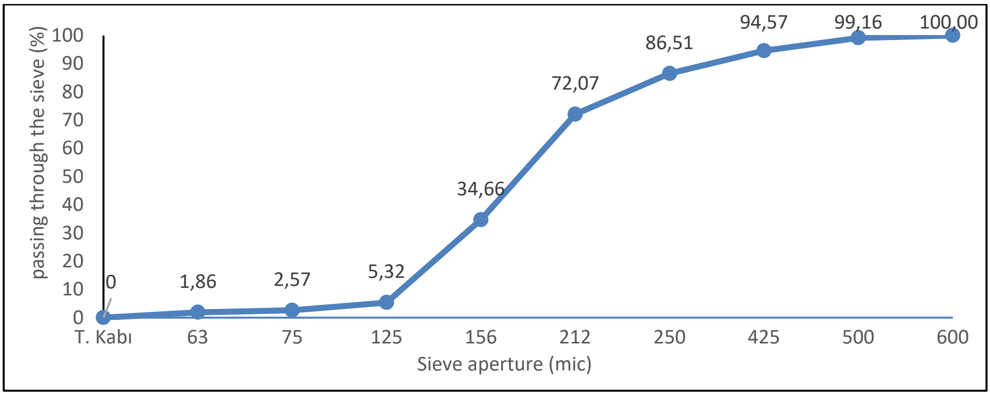


Fig. 1 Sieve analysis graph of limestone powder

Table 2. Physical properties of limestone powder

Cramped Unit Volume Weight (kg/dm³)	Loose Unit Volume Weight (kg/dm³)	Specific Gravity	Water Absorption (%)
1,62	1,43	2,48	8,068

2.2 Waste Foundry Sand

Foundry sands are of two types: natural sand and synthetic sand. Natural sands are used as obtained from nature. They are used as molds for the casting industry. The sands to be used as casting molds must be in the form of dough and must have properties such as taking shape, not sticking to the hot casting material, forming a smooth surface, and not melting under heat.

Although it varies according to the materials used, bentonite clay is used at a rate of 4-10% as surface smoothness and binder to ensure good molding, and carbon additive (coal dust in general) is used at a rate of 2-10% to prevent the casting material from sticking to the mold. The foundry sand can be used as molds in varying numbers (2-5 times) depending on factors such as the metal to be cast and the casting temperature. Then, it turns into waste and is stored in waste disposal facilities.

The sieve analysis results of the material obtained as waste from the Alaşım Casting Plant are given in Table 3 and Fig. 2, physical properties in Table 4, and chemical compositions in Table 5.

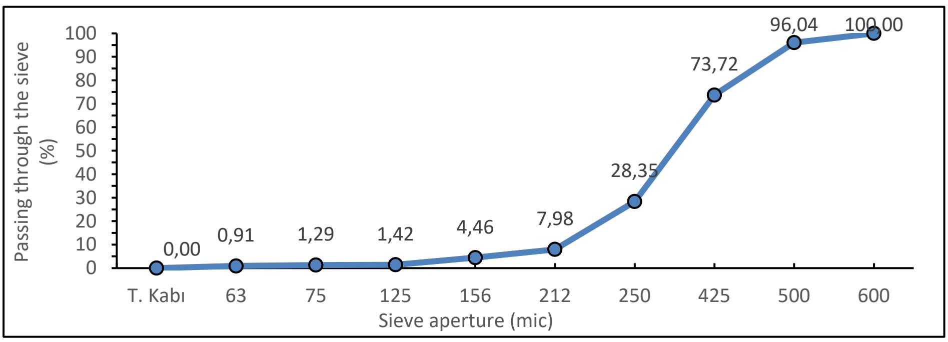


Fig. 2. Sieve analysis graph of waste foundry sand

Table 3. Sieve analysis table of waste foundry sand

Sieve Aperture (mic)	On the Sieve Remainder (gr)	Cumulative Remaining On The Sieve (gr)	Cumulative Remaining (%)	Cumulative Passing Through The Sieve (%)
600	0	0	0,00	100,00
500	39,5	39,5	3,96	96,04
425	222,4	261,9	26,28	73,72
250	452,2	714,1	71,65	28,35
212	203	917,1	92,02	7,98
156	35,1	952,2	95,54	4,46
125	30,2	982,4	98,58	1,42
75	1,3	983,7	98,71	1,29
63	3,8	987,5	99,09	0,91
T. Kabı	9,1	996,6	100,00	0,00

Table 4. Physical properties of waste foundry sand

Technicial Specifications	Cramped Unit Volume Weight (kg/dm^3)	Loose Unit Volume Weight (kg/dm^3)	Specific Gravity	Water Absorption (%)
Value	1,3	1,2	2,44	4,51

Table 5. Chemical analysis results of waste foundry sand

Component	SiO_2	Al_2O_3	LOI	Fe_2O_3	TiO_2	CaO	Cr_2O_3	K_2O	MgO	ZrO_2	P_2O_5	SO_3
(%)	96,45	1,18	0,893	0,51	0,4251	0,2144	0,146	0,081	0,067	0,066	0,019	0,018

2.3 Plasticizer

High-performance superplasticizers were used as plasticizers in the preliminary experiments, and different models of the same brand were used. Technical specifications of the chemicals are given in Table 6. The letter 'A' was used as a code instead of the brand name. The models belonging to the brand will be labeled with letters such as x, y, and z next to the letters, and 'O' will indicate the old date, and 'N' will indicate the new date. Accordingly, the codes Ax, AyN, AyO, and Az will be used.

Table 6. Technical specifications of plasticizers

Technicial Specifications	Ax (2023)	AyO (2020) and AyN (2023)	Az (2023)
Specific weight	1,018 -1,058 kg/lt	1,082 – 1,142 kg/lt	1,069 – 1,109 kg/lt
pH value	5 – 7	6 – 7	5-7
Alkaline content (%)	≤ 3,00 (by weight)		
Chloride ion content (%)	≤ 0,10 (by weight)		
Corrosion behavior	Only includes components listed in EN 934-1:2008, Annex A.1		
Dangerous materials	Fully compliant with Annex-AZ.		
The essence of the material	Polycarboxylic Ether Based		
Appearance	Brown - liquid		

2.4 Fly Ash

Fly ash was obtained from the Çayırhan Thermal Power Plant Ash Separation Plant. The chemical composition of fly ash is given in Table 7.

Table 7. Chemical and physical analysis results of fly ash

Component (%)		Physical characteristics (%)	
SiO_2	52,83	Liter Weight (kg/lt)	1,03
Al_2O_3	10,60	Density (gr/cm^3)	2,42
Fe_2O_3	9,10	Fineness 90 µm (%)	1,70
CaO	8,82	Fineness 45 µm (%)	27,4
MgO	3,48	Free lime (%)	0,75
Na_2O	2,84	28 Days of Activity (%)	77,4
K_2O	1,63		
LoI	0,59		
SO_3	2,90		
Cl	0,0078		

2.5 Cement

Portland cement was used as the material for the preparation of mortars. The cement used is CEM I 42,5 R type Portland cement produced in Afyon ÇİMSA cement plants according to TS EN 197-1 standard. The technical specifications table of this cement is given in Table 8.

Table 8. Technical properties of Afyon ÇİMSA CEM I 42.5 R type cement

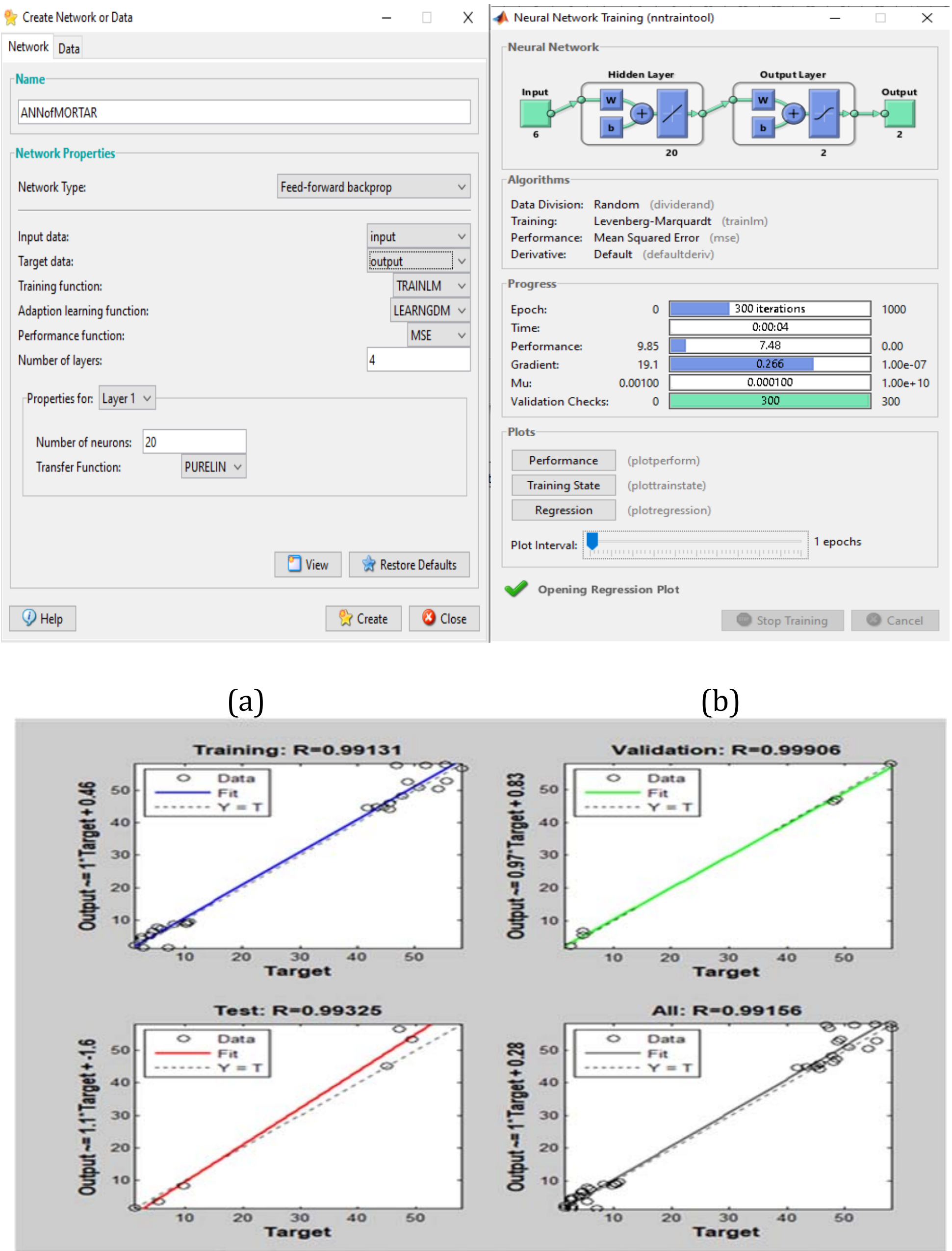
Physical characteristics	Factory data	Standart limits (EN 197-1) Min.	Max.
Specific Weight	3,13 gr/cm^3		
Specific Surface	3600-4000 cm^2		
Initial Setting	140-180 dakika	60	
End Setting	210-70 dakika		
Water	%26-27		
Volume Constancy	1.0 mm		20
2 Day Compressive Strength	29-33 MPa	20	
28 Day Compressive Strength	53-57 MPa	42,5	62,5

3. Metod

This study is the result of preliminary experiments of a doctoral thesis. The thesis is about the use of waste-foundry sand in Sifcon concrete. For this reason, the primary material of the research is to ensure the compatibility of the materials by using waste foundry sand (WFC), which is the waste of the foundry industry, in different ratios. In addition to the plasticizer, the effects of the pozzolanic materials fly ash and silica fume on the fresh state properties were also investigated, and material preferences were made. Ten different mixtures with silica fume (SF) and 14 different mixtures with fly ash (FA) were prepared in order to test the amount of pozzolan, pozzolan type, and pozzolan compatibility with other materials and to select the appropriate pozzolan. In addition, the effect of the type of plasticizer on workability with pozzolanic material was also investigated. All plasticizers were different models of the same brand. At the same time, the performance of one of these chemicals, which has a shelf life of one year, has been on the shelf for three years and has become stale, and its new plasticizer was tested. Here, the effect of exceeding the shelf life on workability was evaluated. For this purpose, mini-slump spreading diameter and mini V-funnel flow time tests were performed according to EFNARC [24].

The planetary mixer used in the mixtures has a capacity of 5 liters and two speeds. It mixes at 140.5 rpm at slow speed and 125.1 rpm at high speed. During the production of mortar samples, powder materials were placed in the mixer and mixed for three minutes.
Then, water was added slowly except for the amount reserved for the plasticizer-water solution.
After all the water was added, the mixture was mixed for two minutes, and the plasticizer solution was added and mixed for two more minutes. Fresh state experiments of mini-spreading followed by V-funnel flow time test were performed.

An artificial neural network (ANN) model (Fig. 3a) was created with six input and two output parameters (Fig. 3b). The input parameters are cement amount, fly ash, water, plasticizer, stone powder, and foundry sand amounts.
Spreading diameter and flow time parameters were given as output parameters. With modeling, flow time and spreading diameter of three different untested mixtures were predicted. ANN model; Network Type: Feed-forward backprop, training function: TRAILNM, Adaption learning function: LEARNGDM, Performance function: MSE, Number of layers: 4, Number of neurons: 20, Transfer Function: PURELIN and Max fails: 300. As can be seen in Fig. 3c, the regression results of the experimental results are shown as Training: R=0,99131, Validation R=0,99906, Test: R=0,99325 and All: R=0,99156.



(c)

Fig. 3. (a) Network generation (b) Input, hidden and output layer (c) Analysis regression results

Mixture amounts and names were determined, as shown in the table. Mixture names were determined according to the initials and (%) ratios of the materials used.
Mixtures according to pozzolanic materials: Silica fume mixtures are given in Table 9, and fly ash mixtures are given in Table 10; both of these tables are 800 dosage mixtures. Mixtures with 1000 kg dosage are given in Table 11.

Table 9. Mixing quantities of silica fume admixed concretes (kg)

Mixture Name	Cement	Pozzolan	Water	Plasticizer	Stone powder	Waste Foundry Sand
WFS10SF10	800	80	264	24	939.22	102.73
WFS5SF20	800	160	288	24	849.18	44.00
WFS10SF20	800	160	288	24	804.49	88.00
WFS20SF20	800	160	288	24	715.10	175.99
WFS20SF25	800	200	300	24	655.22	161.26
WFS20SF30	800	240	312	24	595.34	146.52
WFS25SF20	800	160	288	24	670.40	219.99
WFS35SF20	800	160	288	24	581.02	307.99
WFS35SF20W0,35	800	160	336	24	503,64	266,97
WFS10SF20P0,02	800	160	288	16	821,17	89,82

Table 10. Fly ash additive mixtures (kg)

Mixture Name	Cement	Pozzolan	Water	Plasticizer	Stone powder	Waste Foundry Sand
WFS0FA20	800	160	288	24	910,27	0
WFS5FA20	800	160	288	24	864,76	44,81
WFS10FA20	800	160	288	24	819,24	89,61
WFS0FA30	800	240	312	24	768,77	0,00
WFS25FA20	800	160	288	24	682,70	224,03
WFS30FA20	800	160	288	24	637,19	268,83
WFS25FA30	800	240	312	24	576,57	189,20
WFS30FA30	800	240	312	24	538,14	227,04
WFS40FA20	800	160	288	24	546,16	358,44
WFS25FA40	800	320	336	24	470,45	617,51
WFS75FA20	800	160	288	24	227,57	672,08
WFS100FA20	800	160	288	24	0,00	896,11
WFS100FA30	800	240	312	24	0,00	756,81
WFS100FA40	800	320	336	24	0,00	617,51

Table 11. Amounts (kg) of mixtures with 1000 kg cement amount

Mixture Name	Cement	Pozzolan	Water	Plasticizer	Stone powder	Waste Foundry Sand
WFS0FA30	1000	300	390	30	340	0,00
WFS30FA20	1000	200	360	30	362,49	152,93
WFS100FA30	1000	300	390	30	0,00	335,65
WFS30FA20W0,35	1000	200	420	30	258,33	104,16

After the mixture was prepared (Fig. 4a), the flow time was measured with a mini-v funnel (Fig. 4b), and the spreading diameter was measured with a mini funnel (Fig. 4c) in accordance with EFNARC [24].

Fig..4. (a) Preparation of mixtures (b) Conducting the mini V-funnel test (c) Conducting the spreading test

4. Results and discussion

Since self-compacting concrete properties were targeted in mortar production, the materials with the best workability properties were selected. For this purpose, different materials were tested, and the most suitable ones were selected, and the next material was tested. In the selection of pozzolanic materials to be used in the mixture, spreading and flow time experiments were carried out for fly ash and silica fume options. Mixtures were made with silica fume at different ratios, and spreading and flow time tests were carried out on these mixtures.

Mixing ratios: Substitute silica fume in proportion to cement dosage, substitute foundry sand in proportion to limestone volume, fixed w/b (0.3), and plasticizer amount in proportion to cement dosage (3%) were used. Apart from these ratios, a mixture with an w/b ratio of 0.35 and a mixture with a plasticizer ratio (2%) was tested with one variable compared to the other mixtures.

The abbreviations WFS for waste foundry sand ratio, FA for fly ash ratio, P for plasticizer ratio, and W for w/b ratio were used in the mixture names. The abbreviations P and W were not given in the mixtures with constant (0,30), but only in the series with different w/b ratios.

The research started with experiments to select the plasticizer. For this purpose, the data obtained as a result of spreading and flow time experiments with the same brand but different model plasticizers are shown in Fig. 5. Accordingly, the lowest spreading diameter was 37.5 cm in mixtures using an Ax plasticizer. The second lowest spreading diameter was given by Aye, which was 40 cm. Az 42 cm and Ayy 42 cm gave the same spreading results. In the comparison of old and new model chemicals, one of the fluidizers produced only one month ago, while the fluidizer produced three years ago gave 2 cm less spreading diameter.

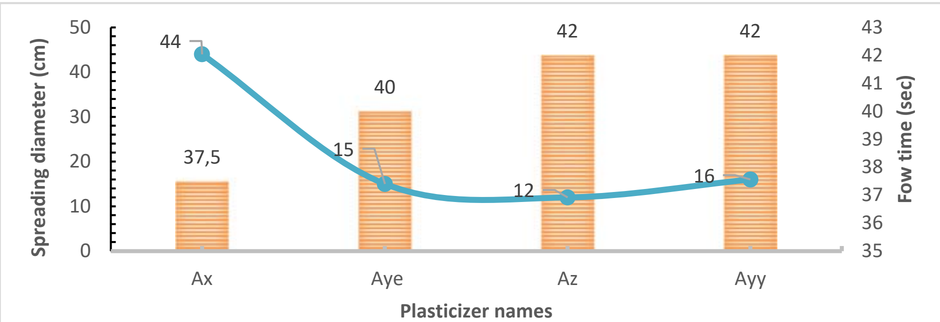


Fig. 5. Test results of spreading and flow time of fly ash series

When the flow times were analyzed, Ax gave the worst performance with a result of 44 seconds, as in the diffusion experiment. Ayy gave the second longest time, 16 seconds. Axe realized the flow in 15 seconds. Az gave the best flow time of 12 seconds. When the old-new comparison is made, Aye gave the result of 15 seconds and Ayy 16 seconds. Although it is old, it gave better results than the new-dated plasticizer. As a result, it is seen that the old chemical gives close results with the new production chemical despite waiting on the shelf for three years. When the results of the two experiments were compared, it was seen that Az-coded Plasticiser gave the best result, and Ayy-coded Plasticiser was in second place with results close to it. According to these results, the Az plasticizer, which gave the best results, was used in the continuation of the research.

A spreading test of the mixtures made with silica fume was performed, and the results are given in Fig. 6. The diffusivity measured as 40.53 cm in the WFS10SF10 series decreased to 38.72 cm in the WFS5SF20 series, where the SF decreased to 5%. In the WFS10SF20 series, where the SF was increased to 20%, the spread increased to 41.40 cm. In the WFS20SF20 series, where the SF was increased to 20%, the spread continued to increase to 43.52 cm. In the new mixture WFS20SF25 series, where the increase in SF was continued, a spread of 45.76 cm and 49.06 cm was obtained in the WFS20SF30 mixture. Compared to the WFS20SF20 mix (43.02 cm), the WFS25SF20 mix gave a higher result with 44.72 cm. This once again shows that the increase in foundry sand causes an increase in the spread diameter. Based on this, a WFS35SF20 mixture was produced, and a 43,67 cm spreading diameter was obtained. This result shows that the increase in foundry sand (WFS) causes a decrease after this ratio. By increasing the w/b ratio of the WFS35SF20 mixture to 0.35, a spreading diameter of 51.70 cm was obtained. Although the increase in the water/binder ratio gave the highest spreading value among the mixtures, this ratio was considered unusable since the increase in the amount of water was seen to cause segregation. In order to see the effect of the amount of plasticizer, the WFS10SF20 (41.4 cm) mixture with 3% plasticizer was repeated with 2% plasticizer, and a 36.25 cm spread was obtained.

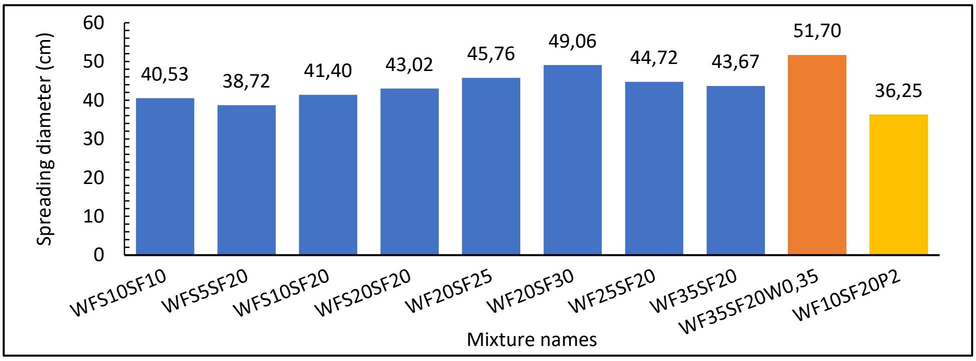


Fig. 6. Results of the spreading test of silica fume and foundry sand substituted mortars

Another experiment applied to the mixtures is the flow time experiment obtained with V-funnel. The results of the experiment are shown in Fig. 7. In the WFS10SF10 series, a flow time of 11.23 seconds was measured. It decreased to 9.59 seconds in the WFS5SF20 series, where the foundry sand substitution decreased to 5%. In the WFS10SF20 series, it was observed that increased silica fume decreased the flow time to 5.61 seconds compared to the WFS10SF10 series. In the WFS20SF20 series, where the foundry sand substitution was increased to 20%, a flow time of 4.77 seconds was measured. Both the increase in SF and the increase in foundry sand had a positive effect on the flow time. In the WFS20SF25 series, which is a new mixture for the use of silica fume at higher rates, a flow time of 1.96 seconds was obtained [25]. In the WFS20SF30 mixture, where the increase of silica fume was tested at a rate of 30%, a flow time of 2.75 s was obtained. It was observed that the flow time increased at this SF rate. Upon this result, the flow time decreased to 2.30 s in the WFS25SF20 mixture, in which the silica fume was reduced to 20%, and the WFS ratio was increased to 25%. Since it was seen that the increase in foundry sand shortened the flow time, the maximum utilization rate was sought by increasing the foundry sand substitution ratio again.

For this purpose, a flow time of 3.76 seconds was measured with the new mixture WFS35SF20. With this result, it was seen that the foundry sand (WFS) decreased the machinability. Considering that the water absorption of bentonite in the foundry sand causes this situation, the WFS35SF20 mixture was mixed at a ratio of 0.35 w/b. The flow time of the WFS35SF20 mixture was measured as 1.58 seconds. However, this was achieved by increasing the amount of water, in which case the strength decreases, and the segregation effects of increasing the water content should be considered [26]. In order to investigate the effect of the plasticizer ratio on the flow time, the experiments were repeated by reducing the plasticizer ratio of the WFS10SF20 mixture from 3% to 2%. In the flow time experiment, a result of 13.7 seconds was obtained, which was the highest of all experiments.

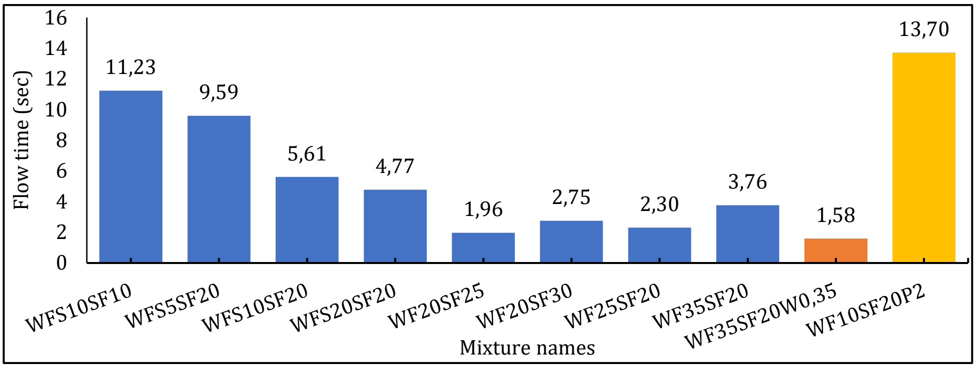


Fig. 7. Flow time test results of silica fume and foundry sand substituted mortars

The flow time and spreading test results of fly ash pozzolan were measured. Silica fume (SF) and fly ash (FA) doped mixtures were prepared for the compatibility of 20% pozzolan with 5% DC, 10% pozzolan with 10% DC and 20% pozzolan with 20% DC. These mixtures were named as WFS520SF- WFS520FA, WFS10SF10-WFS10FA10, WFS25SF20-WFS25FA20 respectively. With these mixtures, spreading with a mini spreading funnel and flow time experiments with a mini V-funnel were carried out.

Mixtures of 20% silica fume, 5% foundry sand, and 20% fly ash, 5% foundry sand, were prepared. The same experiments (spreading, flow time) were performed on the mixtures and given in Fig. 8. The prepared mixtures were labeled as WFS5SF20 and WFS5FA20.

In the spreading diameter test performed with a WFS5SF20 mixture, it was calculated as 38.72 cm. The spreading result of the WFS5FA20 mixture produced with the use of fly ash by changing the pozzolan at the same mixture ratios was 41.75 cm. In the mixture with 5% foundry sand and 20% pozzolan, the mixture with fly ash gave 7.83% higher results than the mixture with silica fume in terms of spreading diameter. New mixtures were made to see the change in workability when the amount of foundry sand and pozzolan were equal. The spreading diameter of 40,53 cm was calculated in the spreading test with the WFS10SF10 mixture. WFS10FA10 mixture was obtained by using fly ash as pozzolan with the same mixture ratios. The spreading test result of the WFS10FA10 mixture was calculated as 44.57 cm. In the mixture with 10% foundry sand and 10% pozzolan, the mixture with fly ash gave 9.97% higher results than the mixture with silica fume in terms of spreading diameter.

According to the WFS5SF20 series, the spread results of the WFS10SF10 mixture showed an increase of 4.67%. WFS10FA10 mixture showed an increase of 6.75% compared to the WFS5FA20 mixture.

Since WFS10 P10 mixtures gave higher results than WFS5P20 mixtures for both pozzolanic additives, it was foreseen to increase the proportions. The new mixture ratios were determined as WFS25P20. The spreading result of the produced WFS25SF20 mixture was calculated as 44.72 cm, and the spreading diameter of the WFS25FA20 mixture was calculated as 45.52 cm. According to the test results, in terms of spreading diameter in the mixture with 20% foundry sand and 20% pozzolan, the mixture with fly ash gave 1.79% higher results than the mixture with silica fume. WFS25SF20 mixture gave a 10,83% higher spreading result than the WFS10SF10 mixture and a 15,50% higher spreading result than the WFS5SF20 mixture. WFS25FA20 mixture gave a 2.13% higher spreading result than the WFS10FA10 mixture and a 9.03% higher spreading result than the WFS5FA20 mixture.

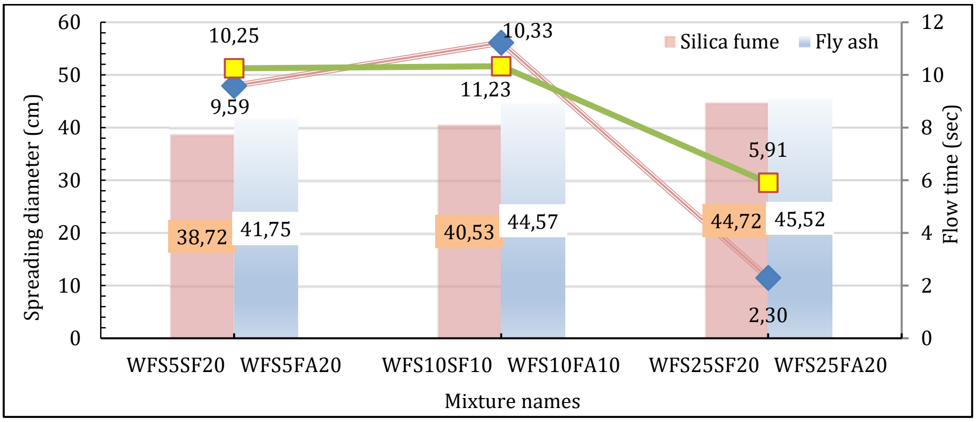


Fig. 8. Flow time and spreading test results of mixtures using silica fume and fly ash

Flow time experiments of the mixtures were carried out with V-funnel. According to the experiments, the result of the flow time experiment with the WFS5SF20 mixture was calculated as 9.59 seconds. The result of the flow time experiment of the WFS5FA20 mixture produced with the use of fly ash by changing the pozzolan at the same mixture ratios was 10.25 seconds. In the mixture with 5% foundry sand and 20% pozzolan, the mixture with silica fume gave 6.88% lower results than the mixture with fly ash in terms of flow time. In the v funnel experiment with the WFS10SF10 mixture, a flow time of 11.23 seconds was calculated. WFS10FA10 mixture was obtained by using fly ash as pozzolan with the same mixture ratios. The flow time of the WFS10FA10 mixture was calculated as 10.33 seconds as a result of the experiment. In terms of flow time in the mixture with 10% foundry sand and 10% pozzolan, the mixture with fly ash gave 8.71% lower results than the mixture with silica fume. Compared to the WFS5SF20 series, the flow time results of the WFS10SF10 mixture increased by 14.6%. WFS10FA10 mixture showed an increase of 0.78% compared to the WFS5FA20 mixture.

The flow time of the produced WFS25SF20 mixture was 2.3 s, and the flow time of the WFS25FA20 mixture was 5.91 cm. According to the test results, in terms of flow time in the mixture with 25% foundry sand and 20% pozzolan, the mixture with fly ash gave 23.9% lower results than the mixture with silica fume. WFS25SF20 mixture gave 74.85% lower results than the WFS10SF10 mixture and 76.02% lower results than the WFS5SF20 mixture. WFS25FA20 mixture gave a 42.79% lower result than the WFS10FA10 mixture and a 42.34% lower result than the WFS5FA20 mixture.
In terms of flow time, the use of silica fume gave better workability results in 2 mixtures and the FA in one mixture. However, since the FA gave better results in terms of spreading diameter in 3 different mixture ratios, it was preferred to determine fly ash as a pozzolan to be added to the mixture.

Spreading tests were carried out by increasing the foundry sand in the tests carried out with Az chemical. The results of the tests are given in Fig. 9. According to the spreading tests performed by replacing limestone powder with foundry sand, 45,6 cm was measured in WFS0, 41,75 cm in WFS5 series, 44,57 cm in WFS10 series, 45 cm in WFS15 series, 45,52 cm in WFS25 series, 48,42 cm in WFS40 series and 47,83 cm in WFS50 series, 50,53 cm in WFS75 mixture and 49,30 cm in WFS100 mixture. WFS5, WFS10, WFS15, WFS15, WFS25 and WFS25 gave lower spreading diameters by 8.44%, 2.26%, 1.32% and 0.18%, respectively, compared to the spreading result of WFS0 series. WFS40 series gave 6.18%, WFS50 4.89%, WFS75 10.81% and WFS100 8.11% larger spreading diameter than WFS0. WFS10 mixture measured 6.75% higher spreading diameter than WFS5, WFS15 0.96% higher than WFS10, and WFS25 1.16% higher than WFS15.

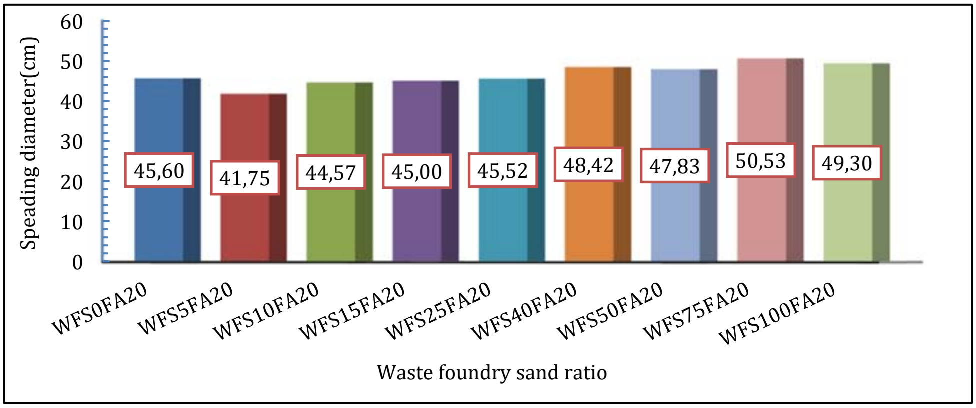


Fig. 9. Results of the spreading test with increasing foundry sand

V funnel flow times of the same mixtures were 10.85 s for WFS0, 10.25 s for WFS5 series, 10.33 s for WFS10 series, 9.75 s for WFS15 series, 5.91 s for WFS25 series, 4.79 s for WFS40 series, 2.49 s for WFS50 series, 1.50 s for WFS75 mixture and 1.35 s for WFS100 mixture. Compared to the flow time result of WFS0 series, WFS5, WFS10, WFS15, WFS25, WFS40, WFS50, WFS75, WFS75, and WFS100 gave a smaller flow time result of 5.53%, 4.79%, 10.14%, 45.53%, 55.85%, 77.05%, 86.18%, and 87.56% respectively. WFS10 mixture showed 0.77% increase compared to WFS5, WFS15 5.61% compared to WFS10, WFS25 39.38% compared to WFS15, WFS40 18.95% compared to WFS25, WFS50 48.02% compared to WFS40, WFS75 39.76% compared to WFS50 and WFS100 10% lower flow time compared to WFS75. According to these results, the largest flow time changes between the series were observed, where the waste foundry sand increased from 15% to 25%, from 40% to 50%, and from 50% to 75%. Generally speaking, increases of 25% gave the highest workability differences compared to the previous series.

The V-funnel flow time test results of the series at the same ratios with the increase in foundry sand are shown in Fig. 10. In WFS0, the reference series without foundry sand, the flow time was 10.85 seconds, 10.25 seconds in the WFS5 series, 10.33 seconds in the WFS10 series, and 9.75 seconds in the WFS15 series. In the WFS25 series, there was a sudden decrease in flow time compared to the series with less foundry sand. While this series completed the flow with 5.91 seconds, the decrease in times continued with the increase in foundry sand. The flow time was 4.79 seconds in the WFS40 series and 2.49 seconds in the WFS50 series.

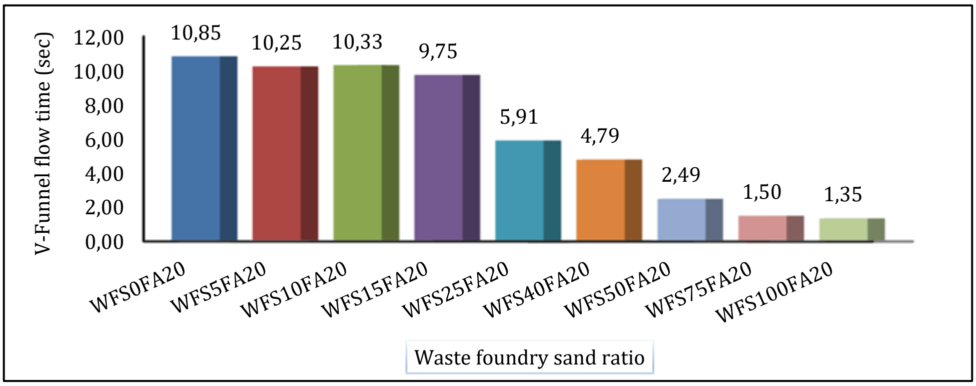


Fig. 10. Relationship between the increase in foundry sand and flow time

The positive effect of the increase in WFS on workability was observed. The effect of fly ash increase, which is thought to be another factor on workability, was analyzed. In order to examine this effect, WFS was analyzed at 0%, 10%, 25%, and 40% substitution. The proportions of the mixtures were kept constant, with fluidizer at 3%, water/binder at 0,30, and cement dosage at 800 kg. As can be seen in Fig. 11, when AWFS was 0%, and fly ash (FA) was 20%, a 45.60 cm result was obtained according to the spreading test results. In the WFS5FA20 mixture, a 41.75 cm spreading diameter was measured. The amount of foundry sand increased from 0% to 5%, causing a decrease of 8.44%. In the use of 20% fly ash, the proportion of foundry sand was increased to 10%, and the spreading diameter was 43.33 cm, which is a decrease compared to the WFS0FA20 mixture but an increase of 3.78% compared to the WFS5FA20 mixture. When the WFS ratio was 0%, and the fly ash ratio was increased to 30%, the spreading diameter reached 54 cm and showed an increase of 18% compared to the WFS0FA20 mixture. When 20% FA was added to the mixture designed as WFS 25%, a diameter of 45.52 cm was reached, and an increase of 5.05% was obtained compared to the spread of the WFS10FA20 mixture. It is seen that this ratio is almost the same with the WFS0FA20 mixture. The spreading diameter measured as 48.10 cm in the WFS30FA20 mixture showed an increase of 5.48% compared to the reference mixture WFS0FA20. In the WFS25FA30 mixture, a spread of 48.67 cm was obtained.
Since it was seen that the highest spreading diameter in these experiments was in the WFS0FA30 mixture with a 30% FA contribution among the FA ratios and in the WFS30FA20 series with a 30% AWFS contribution in terms of foundry sand, the WFS30FA30 mixture, which is 30% FA and 30% WFS series, was tried in the new mixture. The highest spreading diameter, 55.50 cm, was obtained from the WFS30FA30 mixture in the previous experiments.

In the WFS40FA20 mix, where the foundry sand was increased to 40%, it was measured as 48.42 cm. This result showed an increase of 6.18% compared to the WFS0FA20 reference mix and 0.66% compared to the WFS30FA20 mix. According to these results, the increase in WFS increases the spreading diameter. WFS25FA40 mixture was made as a comparison to the WFS25FA30 mixture, and an increase of 3.06% with a spread diameter of 47.18 cm and a 3.65% spread diameter increase compared to the WFS25FA20 mixture was obtained. With the WFS75FA20 series, the foundry sand was increased to a 75% replacement ratio, and a spreading diameter of 50.53 cm was obtained. Compared to the WFS0FA20 mix, the WFS75FA20 mix gave a 10.81% higher spreading result. The WFS100FA20 mix, where 100% of the foundry sand was applied, measured 49.3 cm. Although it showed an increase of 8.11% compared to the WFS0FA20 series, a decrease of 2.43% was observed compared to the WFS75FA20 series. WFS100FA30 mixture was 58 cm, and WFS100FA40 mixture was 46.74 cm.

According to the results, both foundry sand and fly ash increased, causing an increase in the spreading diameter. As mentioned before, a 10% increase in the FA caused the highest spreading increase of 18% in the series with WFS 0%, while a 10% increase in WFS in mixtures with 20% in the FA caused an increase of 6.92%. The highest spreading diameter was measured in the WFS100FA30 series at 58 cm. When the DR was 100%, increasing the FA from 30% to 40% caused a 19.41% decrease in the spreading diameter.

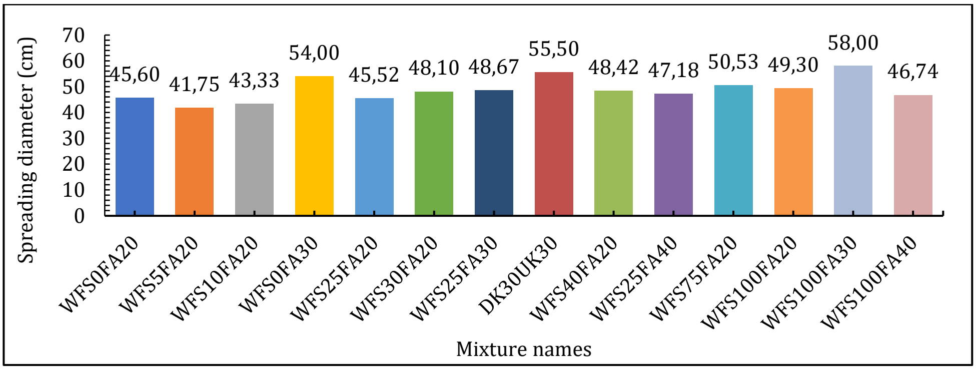


Fig. 11. Results of the spreading test of the foundry sand-fly ash ratio change

Another experiment performed with the same mixture ratios is the flow time experiment obtained by V-funnel. According to the results of the flow time experiment, the flow time of the WFS0FA20 mixture with WFS 0% and FA 20% was 10.85 seconds. The flow time was 10.25 seconds in the WFS5FA20 mixture produced with 5% foundry sand, and the flow time decreased to 8.14 seconds in the WFS10FA20 mixture with 10% waste foundry sand. In the WFS0FA30 mixture, where the WFS ratio was 0%, and the fly ash ratio was increased to 30%, the flow time decreased to 5.36 seconds, and the flow time decreased by 50.6% compared to the WFS0FA20 mixture. In this comparison, adding fly ash up to 30% increased the flow property for the mixture without waste foundry sand. The flow time was 5.91 seconds compared to the flow time of the WFS0FA20 mixture; there was a 45.53% decrease in the WFS25FA20 mixture and a 56.96% decrease in the WFS30FA20 mixture. In the mixtures made so far, it has been observed that the increase in WFS shortens the flow time. Since it was observed that the mixture in which the amount of fly ash was increased from 20% to 30% (WFS0FA30) gave lower flow time results, the WFS25FA30 mixture was produced by increasing the WFS from FA30 to WFS25. This mixture gave a much better flow time result of 3.95 seconds. This result is 26.31% lower than the WFS0FA30 series. The WFS30FA30 mix gave a flow time of 2.59 seconds. The WFS40FA20 mixture was made by increasing the foundry sand, which resulted in 4.79 seconds. This result is 55.85% lower than the WFS0FA20 mix, 41.15% lower than the WFS10FA20 mix, and 18.95% lower than the WFS25FA20 series. The results are shown in Fig. 12.

The WFS25FA40 mixture resulted in a flow time of 5.42 seconds. This result was 37.22% lower than the WFS25FA30 mixture and 50.05% lower than the reference mixture WFS0FA20. However, it is 8.29% lower than the WFS25FA20 mix. The WFS75FA20 mixture, in which the waste foundry sand was increased to 75%, measured 1.5 seconds, and the WFS100FA20 mixture measured 1.35 seconds. According to these results, the increase in waste caster sand shortened the flow time and gave the shortest result of all mixtures. For the effect of fly ash on the workability with 100% WFS, a 30% FA mixture was produced with this ratio of WFS. The produced WFS100FA30 mix gave a flow time of 2.79 seconds, and the WFS100FA40 mix with a 40% FA increase gave a flow time of 7.08

seconds. In the mixtures where the replacement of waste foundry sand was 100%, the best result was given by 20% fly ash additive.

According to the results, both variable materials cause an increase in machinability. The 20%FA additive caused the highest flow time reduction of 50.6% in the WFS0FA30 mix, where it was increased by 10% to FA30, while the 10% increase of WFS in the WFS10FA20 mix caused a 24.88% flow time reduction compared to the WFS0FA20 mix.

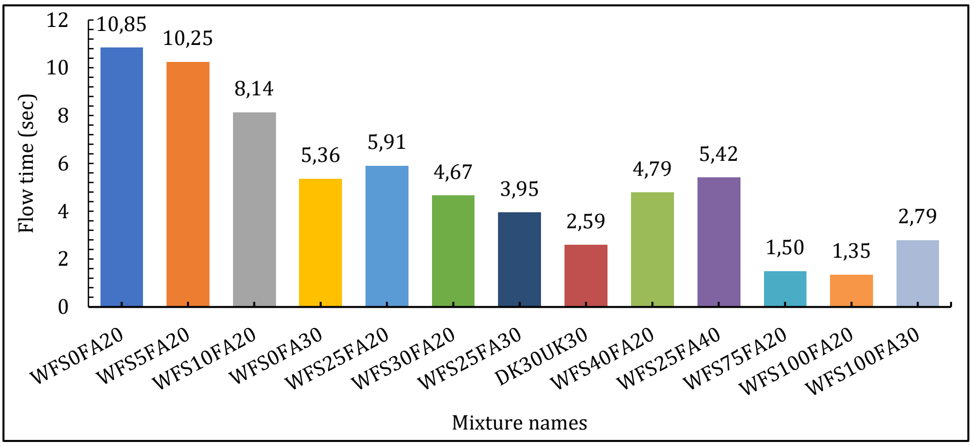


Fig. 12. Results of the flow time experiment of the foundry sand-fly ash ratio change

The last experiments with less plasticizer were mixtures in which the amount of cement was increased to 1000 kg. In these mixtures, spread diameter and flow time comparison (Fig. 13) was carried out with FA%20-%30 ratios with WFS 30% substitution. While the spreading test result was measured as 51.73 cm in WFS30FA20 mixtures, it increased to 55.33 cm in WFS30FA30 mixtures. As it was seen that the increase in WFS increased the test results, the WFS ratio was increased to 100%, and a new mixture was made. In the WFS100FA30 series, the spread increased to 57.79 cm. The targeting of the spread value of the WFS30FA20 mixture with silica fume (SF) was achieved only in the mixture in which the w/b ratio was increased to 0.35. A spread diameter of 51.70 cm was obtained from this mixture.

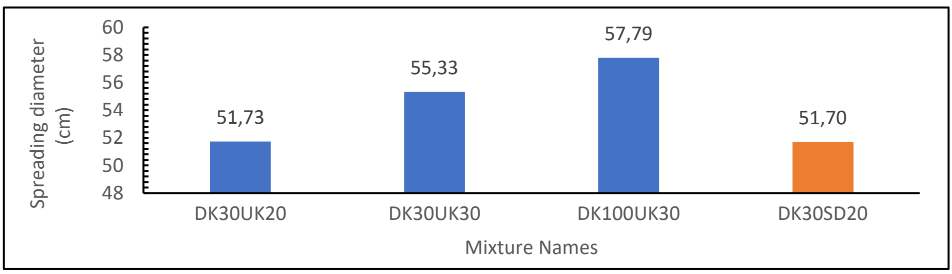


Fig. 13. Results of the dispersion test in mixtures with a dosage of 1000 kg

The flow times of the mixtures where the cement mass was calculated as 1000 kg are given in Fig. 14. The flow time, which was 4.47 seconds in the WFS30FA20 mix, decreased to 2.59 seconds in the WFS30FA30 mix, where the amount of FA was increased to 30%. It was measured as 2.73 seconds in the WFS100FA30 mixture, where the foundry sand ratio was increased to 100%. The flow time of the WFS30SF20 mixture (w/b 0.35), which was tried to have the same spreading diameter as WFS30FA20, gave the lowest flow time result with 1.58.

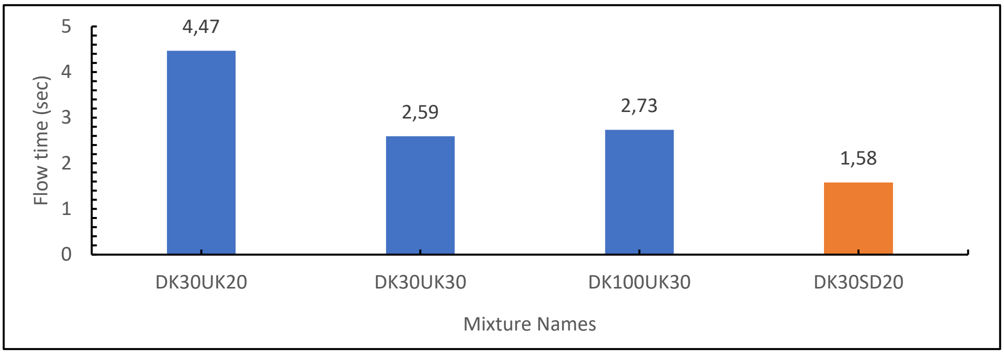


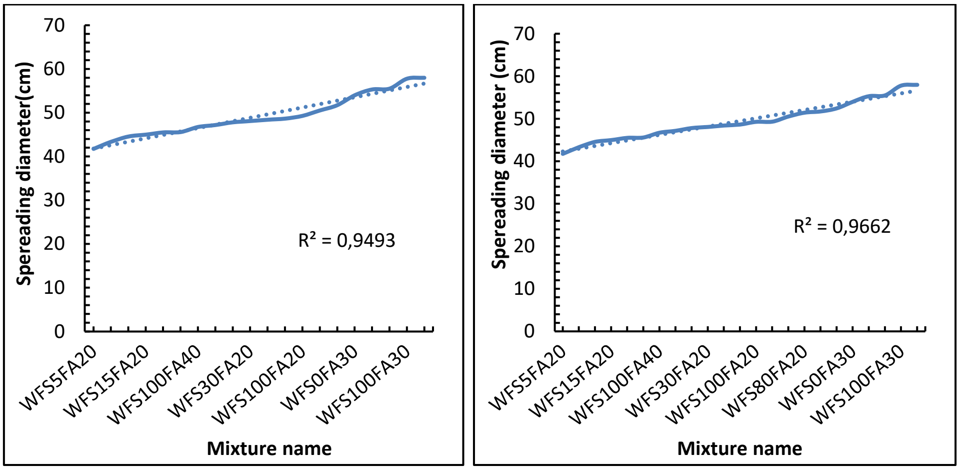
Fig. 14. Flow test results in mixtures with a dosage of 1000 kg

The propagation diameter and flow time results obtained by ANN modelling are given in Table 12.

Table 12. Results obtained from ANN modeling

Mixture Name	Cement (kg)	Pozzolan (kg)	Water (kg)	Plasticizer (kg)	Stone powder (kg)	Waste Foundry Sand (kg)	Spreading diameter (cm)	Flow time (sec)
WFS60FA20	800	160	288	24	364.11	537.67	49.33	3.37
WFS80FA20	800	160	288	24	182.05	716.89	51.45	2.16
WFS90FA20	800	160	288	24	91.03	806.50	52.45	1.84

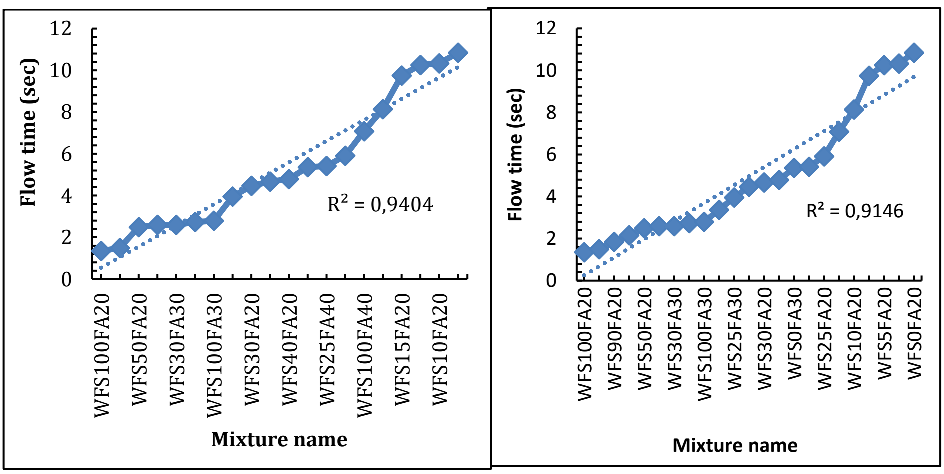
In Fig. 15a, the results of the spreading diameter found by performing the experiments were plotted in an Excel program, and R2 = 0,9493 was obtained. When the spreading test results obtained with ANN were added to the graph (Fig. 15b), R2 = 0.9662 was obtained.



(a) (b)

Fig. 15. (a) Results of the propagation experiment (b) Results of the propagation experiment with ANN results added

When the graphs were drawn in the same way for the flow time experiment, R2 = 0.9023 as seen in Fig. 16a, while R2 = 0.9146 as seen in Fig. 16b when the flow time results obtained with ANN were added.



(a) (b)

Fig. 16. (a) Results of the flow time experiment (b) Results of the propagation experiment with ANN results added.

4. Conclusion

A 4.76% decrease was observed in the spreading test, and a 6.25% decrease was observed in the flow time test of the plasticizer, which had expired its shelf life two years ago, compared to the newly dated product. Although this is not a big loss in terms of product performance, it would be more accurate to comment on its usability by seeing the hard state test results.

While fresh state test results can be improved with variables such as w/b ratio and fluidizer ratio, segregation must be controlled. Otherwise, only the test results can be deceptive.

The increase in foundry sand is related to the increase in SF. Accordingly, workability decreases when SF exceeds 30%, while SF is used at 20%. While SF is at 20%, the use of WFS is more than 30%, which decreases workability again. The mixture with waste foundry sand substitution ratio of 100% at 20% fly ash ratio gave the highest workability results in the mixtures using fly ash (27) . The highest spreading result was obtained when the WFS was 100% and the FA was 30%. However, workability decreased at higher FA results.

Workability increased as the plasticizer increased, but negative results such as water and lime vomiting were also observed.

When fly ash and silica fume were tested at the same mixture ratios, it was observed that fly ash gave better results. However, this difference was pronounced in the spreading experiment, and very similar results were obtained in the funnel. Since silica fume has a finer structure than fly ash, it is thought to result from adsorbed and absorbed water retention.

The effect of increasing the dosage from 800 kg to 1000 kg on workability is almost negligible. Since all materials in the mixtures were fine, cement substitution did not affect the workability in terms of fineness.

In the study carried out with artificial neural networks, it was observed that the R2 value gave results with a reliability above 0.90.

The losses in workability are due to the clay and chemical binders in the WFS, and the increase in clay due to the increase in WFS increases the water absorption (28)(29). The information in the literature generally follows this trend. However, in this study, the increase in waste-cast sand increased the workability. Experiments with different brands of plasticizers and foundry sand wastes will be helpful.

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