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Preparing a New Type of Concrete Based on Sulfur-melamine Modifier

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Abstract

In this research work, a new type of concrete based on sulfur-melamine modification was introduced, and its various properties were studied. This new type of concrete was prepared based on the sulfur-melamine modification and various ingredients. The new sulfur-melamine modifier was fabricated, and its fabrication was confirmed by IR spectroscopy and TG analysis. The surface morphology resulted from this modifier was studied by SEM and EDS analysis. The components ratios in concrete, chemical and physical characteristics resulted from sulfur-melamine modifier, chemical and corrosion resistance of concrete, stability of concrete against water adsorption, stability of concrete against freezing, physical and mechanical properties and durability, modulus of elasticity, and thermal expansion coefficient of the studied sulfur concrete were investigated. The IR results confirmed the amino functional groups (attached melamine ring) and the formation of polymer sulfur chains. The sulfur-melamine modification thermic mass loss was one step. The mass loss processes of the modifier were endothermic processes. The obtained SEM results revealed that the sulfur-melamine modifier had a more porous structure, without any crystal forms. EDS analysis showed that the nitrogen atoms were accounted for 51.33% of total mass while the carbon was 30.94% of total mass. The stability of sulfur-melamine modifier-based concrete was very high in the various aggressive solutions. The low size of aggregates-based concrete had more density, i.e., 2417 $kg\backslash m^3$. The concrete density was decreased slowly with increase in the size of aggregate. The average deformation of studied concrete was (0.0030-0.0033), confirming that the deformation performance of concrete was better than the traditional concretes. The obtained results also confirmed that value of thermal expansion coefficient for sulfur-melamine modified concrete was $17.2\times10^{-6}\backslash^{\circ}C$.

Keywords: Elasticity, Melamine, Modification, Sulfur concrete, Thermal expansion coefficient.

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Introduction

The sulfur-based concrete initially pioneered in the USA, and many research works were done to develop the sulfur type concretes. The research works confirmed that the sulfur concretes were safe materials in the building materials [1-4]. The sulfur is a compound existing in crude oil and gas products. The cost of sulfur is also very low, compared to other basic products. The main role of sulfur in the concrete is acting as a binding material. The sulfur concrete is contained other ingredients as well, such as the rock parts, sands, fly ash and stabilizing materials [5-8]. The sulfur concrete is of a low porosity and contains high-density mixture, and its strength is better than the cement concrete [9,10]. The sulfur and the formed aggregates are mainly responsible for the matrix structures of sulfur concrete [11-13].

The sulfur concrete was mostly used in the offshore structures, dams and underground utility systems. The reason for these kinds of usages is that it has a high strength, high density and low porosity. In the construction industry, Portland cement concrete was the widely employed material [14-16]. However, Portland cement concrete had some drawbacks. For example, more porosity in the structure of Portland cement concrete influence the freezing properties; as a result, the concrete was destroyed in the winter or high humidity conditions [17-20]. In addition, the chemical and corrosion resistance of Portland cement concrete is not good, and its water adsorption performance is high [21]. Also, the physical and mechanical properties and durability, modulus of elasticity and thermal expansion coefficient of Portland cement concrete is not good. However, the sulfur concretes have better performances than the Portland cement concrete [22-24].

In the current work, a new sulfur-melamine modifier was introduced for fabrication of novel concretes. The main aims of present work are as follows:

(i) The new type of concrete based on sulfur-melamine modifier was introduced and its various properties were studied.

(ii) The new sulfur-melamine modifier was synthesized and its structure was confirmed by the IR spectroscopy and TG analysis.

(iii) The surface morphology of this modifier was studied by the SEM and EDS analysis.

(iv) The new concrete type was prepared based on the sulfur-melamine modifier and various ingredients.

(v) The components ratio in concrete, chemical and physical characteristics of sulfur-melamine modified concrete, chemical and corrosion resistance of concrete, stability of concrete against water adsorption, stability of concrete against freezing, physical and mechanical properties and durability, modulus of elasticity and thermal expansion coefficient of studied sulfur concrete were investigated.

Materials and Methods

Materials

The orthorhombic sulfur (sulfur for industrial use. Specifications; Technical sulfur granulated GOST 127.1-93; it was purchased from the open joint-stock company "Shurtan Gas Chemical Complex", Shurtan region, Uzbekistan) and melamine (Melamine. Specifications; GOST 7579-76; it was purchased from the open joint-stock company "Fargonaazot", Fergana city, Uzbekistan) were used in the synthesis of sulfur-melamine modifier. The sulfur is element and has several allotropic forms. The rhombic sulfur is allotropic forms of sulfur. It is crystalline form of sulfur. The eight sulfur atoms are covalently linked each other in the rhombic sulfur.

Methods

IR spectroscopy

The Infra-red (IR) spectroscopy method was employed to explore the structural performance of sulfur-melamine modifier. The IR analysis was carried out by using IR spectra which were recorded on a Bruker Fourier spectrometer, Invenio S-2021, ATR, in the range 4000 – 400 cm^{-1}. The values in the IR shifts are mainly responsible for the vibration of functional groups [25,26].

SEM and EDS analysis

The surface characteristics of sulfur-melamine modifier was explored by the scanning electronic microscopy (SEM) and energy dispersion spectroscopy (EDS) methods. The surface morphology of modifier was explored by the SEM whilst the element analysis of surface was explored by the EDS. The SEM and EDS analyses were done in Jeol JSM-IT200LA [27,28].

Thermogravimetric analysis

The thermogravimetric (TG) analysis of sulfur-melamine modifier was done to explore the heat treatment of compounds. The TG analysis was performed in Thermo Scientific, GC1310 combined Tsq 9000_TA Instiments STD 650 (USA). The temperature ranges were between (100-1000) ºC [29,30].

Measurements of chemical and corrosion resistance of concrete

The stability of concrete in the aggressive chemical and corrosion solutions [31-33] is important factor. In this research work, the stability of sulfur-melamine modifier-based concrete was checked in the various aggressive solutions (All calculations in chemical and corrosion tests were done related GOST R 58896-2020 standards.): 10% acidic solutions (sulfate, chloride, nitrate and phosphate acid), 3% saline solutions (sulfates, chlorides and fluorides salts), 10% NaOH, pH changing medium (pH = 4-10), and organic compounds (car oil, dichloroethane and diesel fuel) [34,35].

Measurements of stability of concrete against water adsorption

The water adsorption of concrete is also an important factor in the estimation of stability of concrete in the aquatic phase and high humidity-containing atmospheric phase. In this work, the stability of sulfur-melamine modified concrete against water adsorption was explored during 30 days by calculating weight mass before and after storage in water. The values in stability coefficient of concrete against water adsorption was measured by following Eq 1:

$$W_A = \frac{M_b - M_a}{M_a} \times 100\% \; \ldots. \qquad 1$$

where M_a is mass of dried concrete (before experiment), M_b is mass of water adsorbed concrete (after water adsorption), and W_A is mass rise after water adsorption which is equivalent to the stability coefficient of concrete against water adsorption [36,37].

Measurements of stability of concrete against freezing

The stability of concrete against freezing was researched in aquatic medium. The 100×100×400 mm prismatic specimens of concrete according to the ASTM C666 procedure were prepared. The relative dynamic modulus of the samples was measured every 50, 100 and 300 cycles. One cycle was 4 h apart and repeated up to 300 times over a temperature range of (4-18) ºC. The study was stopped after 300 cycles. As a result, the stability coefficient of cycles was estimated [38,39].

Determination of elasticity, deformation and durability

In the start of determination of the elasticity, deformation, and durability, the targeted sulfur-melamine modified concrete was prepared for this test as the cylinder-shaped pieces. The dimension of this sample was 20 cm height and 10 cm width. The prepared examples were stored for three days. The elasticity and durability performances of targeted sulfur-melamine modified concrete were checked after three days. The 1500 kN SATECTM Series 1500 HDX (Norwood, MA, US) was applied to measure the elasticity and durability [40,41].

Measurements of thermal expansion coefficient

The value of thermal expansion coefficient shows the concrete efficiency in the conditions of changing temperature. The value of thermal expansion coefficient for sulfur-melamine modified concrete was measured and compared with the traditional concretes, such as the Portland cement concrete. In this analysis, firstly, the concrete samples were immersed in the water during two days at the various temperature ranges, from (4-18) ˚C. After immersion, the length of concrete was measured. As the final step, the changes in the length of the concrete at the various temperatures were measured by a differential transformer. The linear expansion of the samples was measured at 0.2 ˚C/min [42,43].

Experimental part:
Preparation of sulfur modifiers

The orthorhombic sulfur modifier preparation processes were described in Fig 1. In this preparation manner, the orthorhombic sulfur was reacted with the melamine to obtain polymerized forms of the sulfur modifiers. The preparation steps are as follows (It was first time suggested):

(i) 20 g of orthorhombic sulfur moved into heat-resistant beaker and stirred at 185 ˚C for 30 minutes until the formation of transparent solution; as a result, the solution of liquid sulfur is formed.

(ii) In the next step, 1.2 g of melamine was mixed with the solution of liquid sulfur, then the reaction mixture was stirred during 60 min. The reaction temperature was 185-190 ˚C. As a consequence, the copolymers (brown color) of the orthorhombic sulfur and melamine were formed. The viscosity of this copolymer is high.

(iii) In the final process, the formed copolymer was transferred from the chemical beaker to a special container. In the following step, the resulting sulfur copolymer was heated at (185-190) ˚C and stirred until a liquid phase was formed. The reaction temperature was controlled by oil bath. Therefore, the targeted copolymer was achieved.

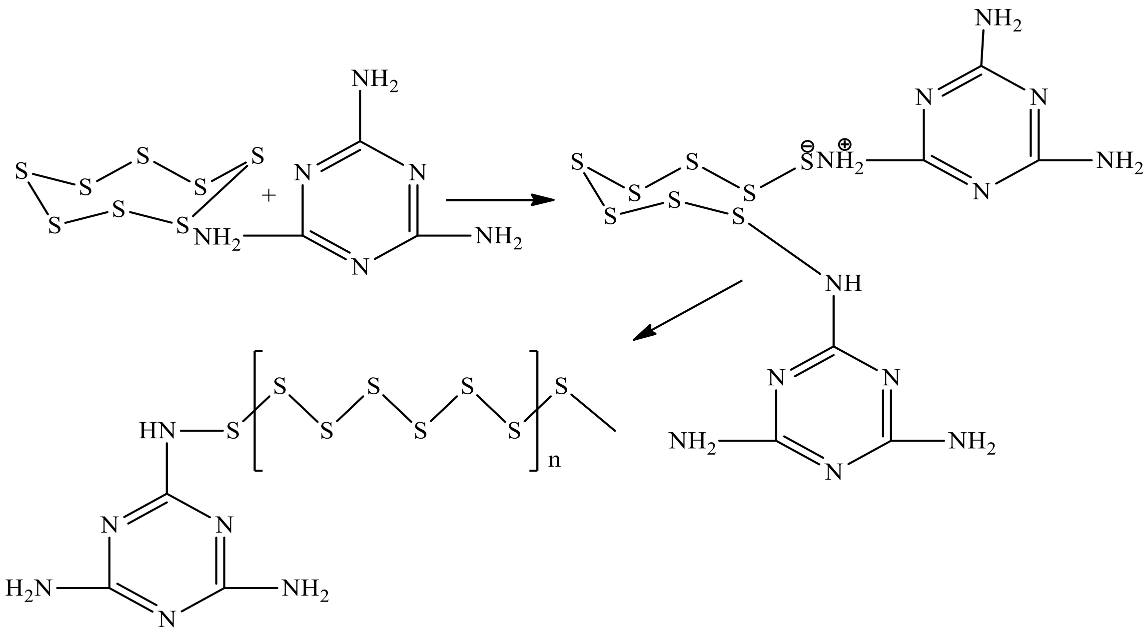

Figure 1. Sulfur modifier preparation processes.

Preparation of sulfur-melamine modified concrete

The preparation steps of targeted concrete based on sulfur-melamine modification was indicated in Fig 2.

In the beginning of the preparation of concrete by the sulfur-melamine modification, the required ingredients (crushed rocks, sands and fly ash) were prepared and are heated at the 180 ˚C for 6 hours. Next, the liquid sulfur-melamine modifier was mixed with the required ingredients (crushed rocks: sands and ash) at the 1:2.5 ratio. Then, the mixture cooled in order to heat it up again to this degree at 140-160 ˚C for half an hour. As final step, the heated mixture was cooled to the room temperature; as result, the targeted sulfur-melamine modified concrete was obtained. In the next results, its mechanical and physical properties were measured.

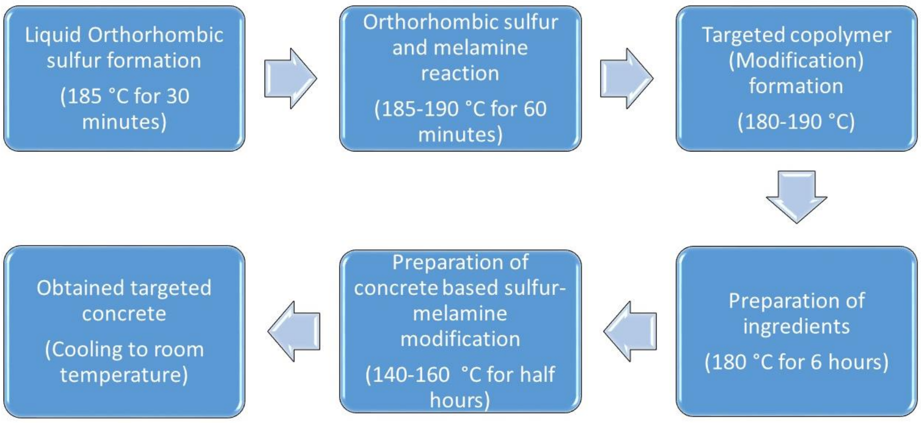

Figure 2. The preparation steps of targeted concrete based on sulfur-melamine modification.

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Results and Discussion

IR analysis

The structural analysis of sulfur-melamine modifier was confirmed by the IR analysis. The obtained IR results of sulfur-melamine modifier was indicated in Fig 3. As can been seen from the resulted spectrum, the valence vibration of amino functional groups (attached melamine ring) was appeared at 3119-3467 cm^{-1}. These signals confirmed the amino functional groups, which are linked with the aliphatic ring of melamine.

It was also indicated in the resulted IR spectrum that the deformational vibrational signals of amino functional groups (attached melamine ring) were found in the 1625 cm^{-1}. The next important signals are related to C=N and C-N bonds. In the 1432-1528 cm^{-1}, the valence vibrations of the C=N bonds were appeared. The valence vibrations of the C-N bonds were found in the 1023 and 1193 cm^{-1} regions.

On the other hand, the melamine linked with the sulfur polymer chains were confirmed by the N-S bonds. The IR signals of N-S bonds were found in the 1649 cm^{-1}. The polymer sulfur chains are built by the S-S bond formation. The (608-810) cm^{-1} IR signals are responsible for S-S bonds [11-13]. Therefore, the obtained IR signals confirmed the structure of sulfur-melamine modifier.

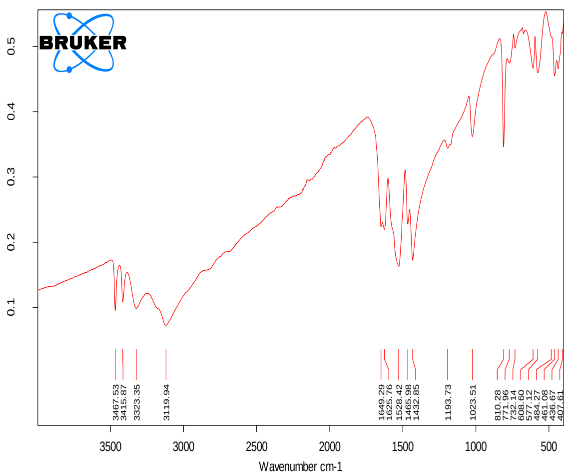

Figure 3. IR results of sulfur-melamine modification.

Thermogravimetric analysis (TGA) analysis

The thermogravimetric (TGA) analysis of sulfur-melamine modifier was done to explore the thermal performances bestowed by the selected modification method. Thermogravimetric curves of sulfur-melamine modifier Fig 4 and its thermogravimetric properties. Table 1 were found. The values in consumed energy (μV*s/mg) weight loss percentage (%) and weight loss (mg) for sulfur-melamine modifier were measured during the temperature changing, from 100-1000 ˚C. As can been seen in the obtained results, the weight loss of sulfur-melamine modifier was stable to 200 ˚C, because the liquefaction temperature of this modifier was 200 ˚C. After 198 ˚C, the mass loss of sulfur-melamine modifier started and was slowly decreased until 230 ˚C. Then, it experienced a dramatical decrease till 324.75 ˚C. The mass loss was 98.482% and the residue was 0.152 mg \1.518%\, confirming that

(i) The modifier concrete was stable up to 198 ˚C.

(ii) The sulfur-melamine modifier thermic mass loss was one-step.

(iii) The mass loss processes of this modifier are endothermic processes, because all peaks are endothermic, which means that the mass loss of this concrete required more extra energy.

In the other hand, the changes in the derivate weight indicated that the sulfur-melamine modifier has one volatilization temperature (peak) at 324.75 ˚C. The heat flow was fluctuated to 250 ˚C, then it was suddenly decreased to 324.75 ˚C, because the volatilization of sulfur-melamine modifier. After this temperature, the heat flow was increased rapidly to 400 ˚C, and it experienced a roughly stable increasing trend.

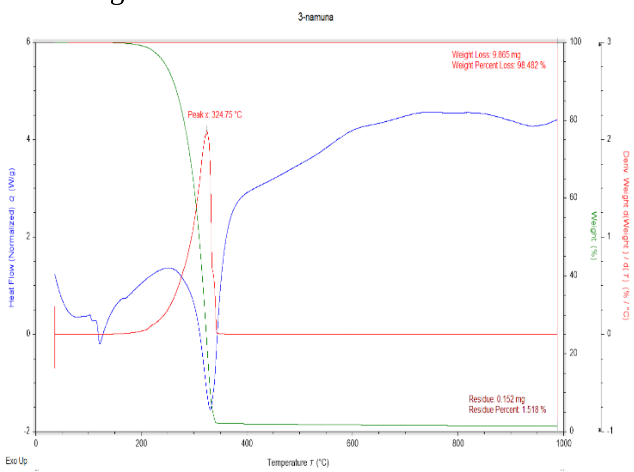

Figure 4. Thermogravimetric curves of sulfur-melamine modifier.

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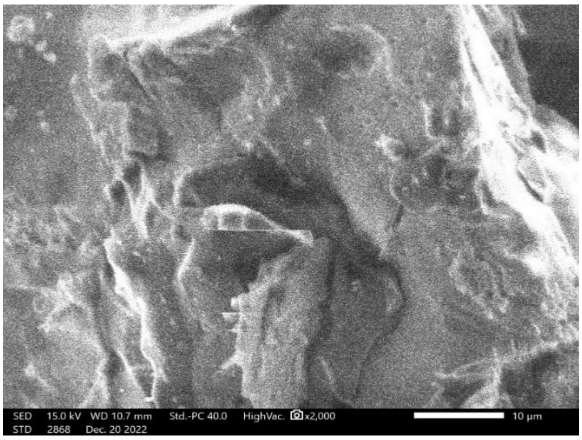
Table 1. Thermogravimetric performances of sulfur-melamine modifier.

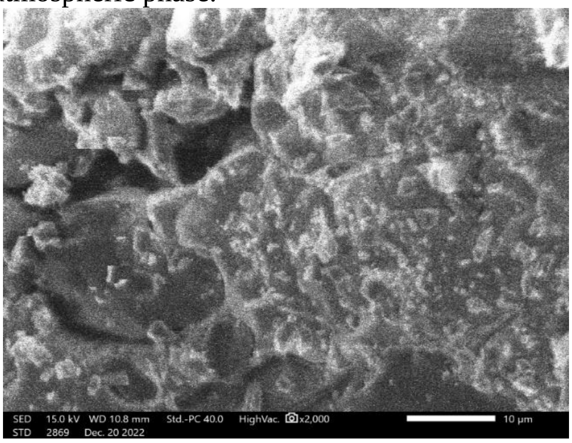
№	Temperature,˚C	Values in consumed energy, µV	Weight loss, %	Weight loss rate, mg/min
1	100	-0.0009	0.018	0.002
2	200	-0.032955	0.796	0.0352
3	300	-1.14236	37.024	0.695
4	400	-0.001423	97.987	1.2024
5	500	-0.001830	98.138	0.003
6	600	-0.00051	98.268	0.0029
7	700	-0.00102	98.352	0.00285
8	800	-0.00113	98.45	0.00284
9	900	-0.000082	98.504	0.00282
10	1000	0.000758	98.902	0.0028

SEM analysis

The surface morphology of sulfur-melamine modifier was investigated by the SEM analysis. Fig. 5 shows the SEM pictures of sulfur-melamine modifier at various size: (a and b) 10 µm; (c) 50 µm and (d) 100 µm. It is clear from the obtained results that the sulfur-melamine modification brings about a structure with more porosity, and there are not any crystal forms in the structure of modifier. Therefore, the sulfur-melamine modifier has an amorphous structure. The sulfur-melamine modification powder is basic part of concrete. The more porosity and amorphous performance of sulfur-melamine modifier increase the efficiency of sulfur-based concrete. It is also revealed that the oxidation products were not found on the surface of sulfur-melamine modifier, confirming that the sulfur based concrete is not oxidised and the oxidation products are not formed. If the oxidation processes were occurred, the obtained concrete was not stable in the atmospheric phase.



A



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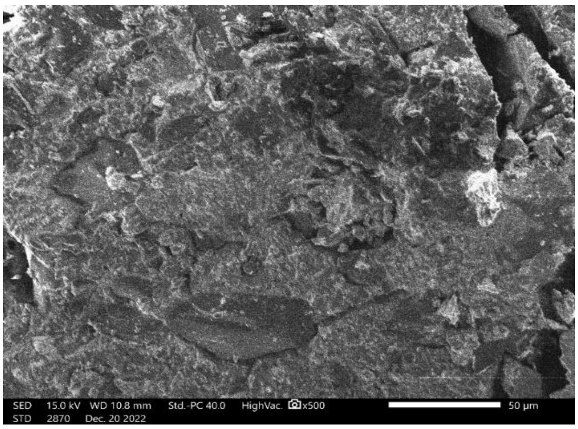

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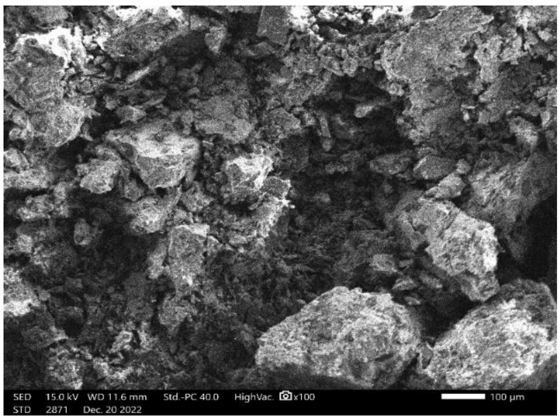

D

Figure 5. SEM pictures of sulfur-melamine modifier concrete at various sizes: (a and b) 10 µm; (c) 50 µm and (d) 100 µm.

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EDS analysis

The surface elemental analysis of sulfur-melamine modifier was done to identify the elemental compositions of the selected modification substance. Fig 6 shows EDS pictures and EDS element map of sulfur-melamine modifier. It was found that the nitrogen atoms were accounted for 51.33% of total mass while the carbon was 30.94% of total mass. These values confirmed the melamine content in the sulfur-melamine modifier. It was indicated that the sulfur content was 17.55% of total mass, confirmed that the studied modifier contained the sulfur element. Therefore, the EDS pictures and EDS element map results confirmed that the sulfur-melamine modifier contained nitrogen, carbon and sulfur elements. In this modifier, the sulfur is bridge element.

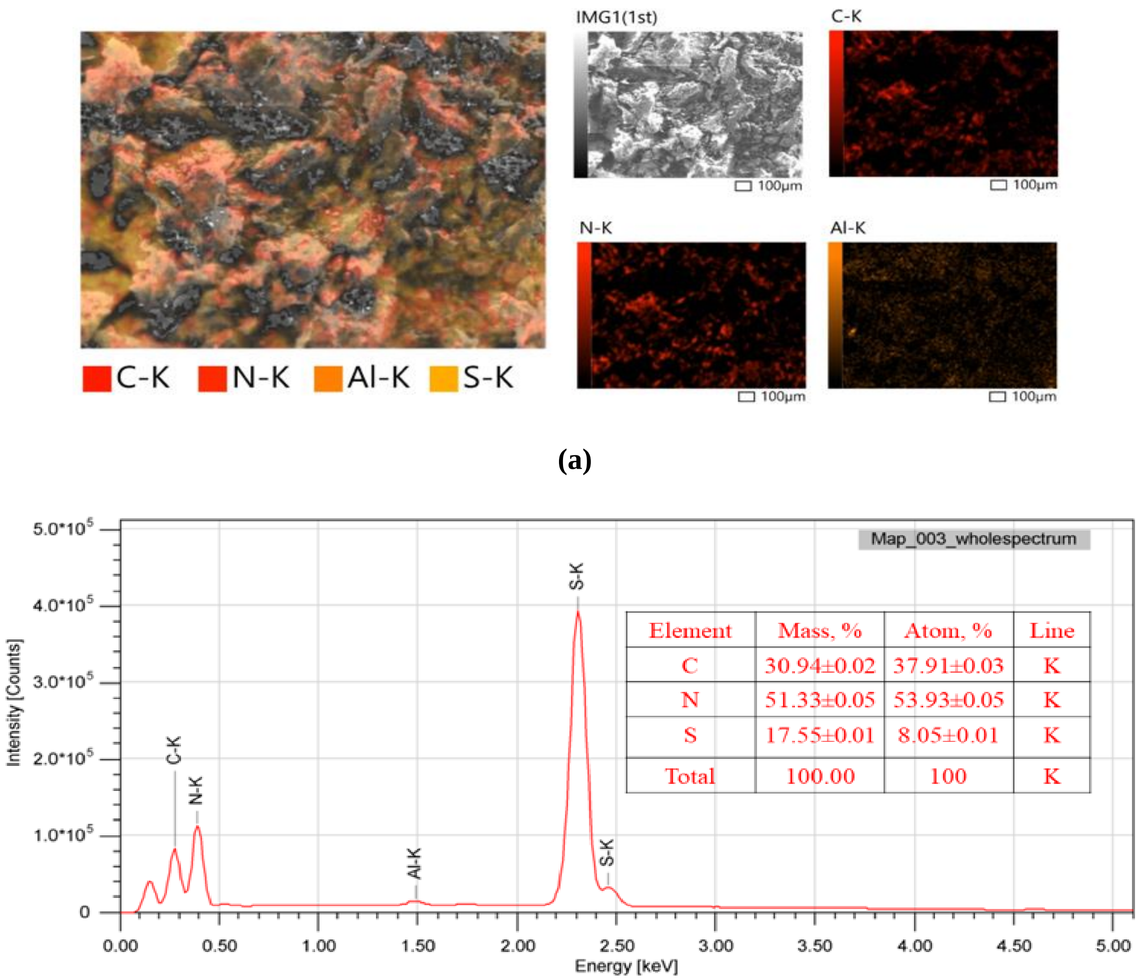

Figure 6. (a) EDS element map and (b) EDS results of sulfur-melamine modifier.

Components ratio in concrete

In this research work, the effective concrete based on the sulfur-melamine modification was obtained. This copolymer is mainly source of sulfur-concrete. In the construction industry, the sulfur-concrete was mostly used. The sulfur-melamine modification substance is a new material among the traditional concretes.

The components ratio in the concrete impacts on the change of various chemical and physical properties. This ratio between the sulfur-melamine modified concrete ingredients were identified by the centripetal force method. It was found in the results of components ratio analysis in concrete that

(i) The more efficient concrete was achieved at the 2:1 ratio (fillers: selected copolymer). In this

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ration, the sulfur modified concrete was high strength and compressive material.

(ii) The 55:45 % (sand: filler) ratio was more effective in the formation of sulfur-melamine modified concrete.

(iii) The large fillers and lower fillers at 36%:30% ratio was more efficient in the formation of concrete.

(iv) The addition of fly ash was found to enhance the easy formability and strength. When the 20% of modified sulfur-melamine was exchanged with the fly ash, the targeted concrete became of easy formability and highest strength.

(v) The volume ratio of modified sulfur-melamine and fly ash of 26:7 % was better for the best concrete preparation.

In the next part of this research, the selection in the preparing concrete was done, relating to the various ratios of ingredients Table.2. The research was done after three days. The five concretes based on the sulfur-melamine modification were prepared with various ratios of ingredients. Then, their various properties were measured. As a result, it was found that:

(i) The example 4 is more efficient than the others are. Maximum size of the large aggregate for example 4 concrete was 25 mm. A type of large aggregate is recyclable.

(ii) The changes in the volume of fly ash and sulfur-melamine modification influence the size aggregate. The volume ration between the fly ash and sulfur-melamine modification at 13.5:17 is best selection.

(iii) The properties of fly ash are also important factors to obtain good concrete based on the sulfur-melamine modification. Table.3 shows the various properties of fly ash in the preparation of sulfur-melamine modified concrete. The value of silicon oxide is 49% in the used fly ash. It is more prominent factor in the enhancing concrete strength. The humidity is very low, 0.1%. The specific surface area is 3.35 m^2/g. Specific gravity was 2.13 g/sm^3. Loss on fire is 3.3%. These properties of fly ash are responsible for the preparation of good sulfur-melamine modified concrete.

Table 2. Selection in the preparing concrete, relating to the various ratios of ingredients.

№	Fly Ash powder (%)		Sulfur-melamine modification, (%)		Small aggregate, (%)		Large aggregate, (%)		A type of large aggregate	Maximum size of the large aggregate (mm)
	Volume	Mass	Volume	Mass	Volume	Mass	Volume	Volume		
I	5.6	5.2	27.2	22.1	30.0	31.9	34	39.2	Natural	19
II	5.6	5.2	27.2	22.1	30.0	31.9	34	39.0	Natural	19
III	15.7	12.5	18.	22.1	30.0	31.7	34	37.4	Natural	19
IV	13.5	14.8	17	12.0	30.0	33.4	34	25.8	Recycled	25
V	17.9	16.0	11.2	22.1	30.0	31.1	34	37.2	Natural	19

Table 3. Measured properties of fly ash in the preparation of sulfur-melamine modifier-based concrete.

Specific surface area (BET), (m^2/g)	Specific gravity, (g/sm^3)	Loss on fire, (%)	Humidity, (%)	SiO_2, (%)
3.35	2.13	3.3	0.1	49

The chemical and physical characteristics brought about by sulfur-melamine modification Table.4. Influence the concrete performance. The basic properties of selected modified concrete were measured. The obtained sulfur-melamine modifier was dark-brown powder and had a good solubility in the CCl_4. This modifier was not soluble in the aquatic solution and was more stable in the aquatic phase. The viscosity of this modifier was high, confirmed that its performance support to prepare better concrete. The density and liquefaction temperature of sulfur-melamine modifier also promote to prepare the effective concrete.

Table 4. The chemical and physical characteristics of sulfur-melamine modifier.

Characteristics	Sulfur-melamine modifier
Color and appearance	Dark-brown powder
Solubility	CCl_4
Viscosity (Newton-second per square metre)	0.075
Liquefaction temperature, ˚C	195
Density, g/sm^3	2.130

Chemical and corrosion resistance of concrete

The chemical and corrosive resistance performance of prepared concrete based on the sulfur-melamine modification was checked and the obtained details were indicated in Table 5. The chemical and corrosion stability of this concrete was investigated in the various aggressive chemical and corrosion solutions. Before doing experiment, the prepared concrete was submerged in the selected aggressive chemical and corrosion solutions for 60 days [44-46]. The values of stability coefficient were measured in this experiment. The maximal value of stability coefficient was 1.0. The experiments were carried after 60 days. If the values of stability coefficient were over 0.5-0.6, the concrete is accounted as more stable while over 0.7-0.8 is responsible for the excellent stabilities. All calculations in chemical and corrosion tests were done related GOST R 58896-2020 standards. It was found that

(i) The chemical and corrosion stability of sulfur-melamine modifier-based concrete in the sulfate, chloride, nitrate and phosphate acid is normal during 2 months.

(ii) The aggressive salts cannot influence the stability of this concrete. The reason for this is that the molecular structure of sulfur-melamine modifier cannot interact with the anodic and cathodic salt ions.

(iii) The chemical and corrosion stability of sulfur-melamine modifier-based concrete was normal in alkaline solutions. The high concentrated alkaline ions are very corrosive. The stability coefficient of this concrete is 0.5, indicating that this concrete is normally stable in the aggressive alkaline solutions.

(iv) The organic compounds, such as car oil, dichloroethane and diesel fuel cannot influence the stability of investigated concrete.

Table 5. Stability effects of sulfur-melamine modifier-based concrete in the chemical and corrosion solutions.

Aggressive chemical and corrosion solution	Stability coefficient (60 days)
10% Acidic solutions:	
\Sulfate acid	0.33-0.51
\Chloride acid	0.52-0.61
\Nitrate acid	0.53-0.62
\Phosphate acid	0.71-0.75
3% Saline solutions:	
\Sulfates salts	0.71-0.81
\Chlorides salts	0.71-0.81
\Fluorides salts	0.90-0.95
10% NaOH	0.51
Medium, pH = 4-10	0.67-0.72
Organic compounds:	
\Car oil	0.66-0.90
\Dichloroethane	0.71
\Diesel fuel	0.85

Stability of concrete against water adsorption

The water adsorption of concrete is also important factor in the estimation of stability of concrete in the aquatic phase and high humidity atmospheric phase. In this work, the stability of sulfur-melamine modifier-based concrete against water adsorption was explored during 30 days by calculating weight mass before and after storage in water. The obtained details were tabulated in Table 6. It was found that

(i) The water adsorption on the surface of sulfur-melamine modifier-based concrete was 0.1-0.37 % and coefficient of concrete against water adsorption was 0.83, indicating that the selected concrete is more stable in the aquatic and high humidity environments. The sulfur-melamine modifier, fillers and other contents of concrete also have effects on the high water resistance of this concrete.

(ii) The deformation of concrete was nearly stable after the water adsorption. The sulfur-melamine modifier is mainly responsible for the high deformation.

(iii) The effect of water been studied on 5 samples of concrete containing different sulfur percentages. As a result, it is suggested that the amount of sulfur in the concrete influence the water resistance of concrete. If the values of sulfur increased, the water resistance would also rise.
This is due to the hydrophobicity of concrete that was enhanced with the rise of sulfur content.

(iv)The low porosity of sulfur-melamine modifier-based concrete also has effects on the values in stability of concrete against water adsorption.

Table 6. Values in stability of sulfur-melamine modifier-based concrete against water adsorption.

Deformation, MPa		Water adsorption, %	Coefficient of concrete against water absorption
Dried	With water adsorption		
51.3	40.0	0.1-0.37	0.83

Stability of concrete against freezing

The freezing of concrete is an important factor in the calculation of concrete efficiency. The values in stability of sulfur-melamine modifier-based concrete against freezing were found for 50, 100 300 cycles and the obtained data was indicated in Table.7. As can been seen from the obtained results, the values in stability of sulfur-melamine modifier-based concrete against freezing was near 1.0, confirmed that the stability against the freezing temperature for this concrete is very high. Therefore, it was suggested that the investigated concrete would be used in the low temperature medium. The low porosity and high sulfur contents of sulfur-melamine modifier-based concrete promote the high hydrophobic performance. As a result, the contact with the water molecules were maximally blocked. The micro pores on the surface of this concrete were very low; this factor is also attributed to rise in the stability of concrete. It is revealed that the freezing stability of concrete depends on the size of the sample, the type and amount of the filler, the conditions of water saturation, the duration of the cycle, the type and amount of the modifier, the freezing temperature and other factors.

Table 7. Values of stability of sulfur-melamine modifier-based concrete against freezing.

Freezing temperature, T	Medium	Stability coefficient of cycles		
		50	100	300
-18 ^{0}C	Water	0.98	0.95	0.90

Physical and mechanical properties and durability of concrete

In the preparation of sulfur-melamine modifier-based concrete, the recycled coarse aggregate, natural coarse aggregate and fine aggregate were used. The basic physical and mechanical properties of these aggregates were found and the results were given in Table. 8. It is revealed that the used recycled coarse aggregates have a lower density and higher water adsorption than natural coarse aggregates. Natural coarse aggregates are crushed aggregates with a maximum size of 25, 19 and 13 mm. The maximum size of recycled coarse aggregate and natural fine aggregate is 25 and 10 mm, respectively.

Table 8. Properties of aggregates used in tests.

Properties		Used aggregates		
		Recycled coarse aggregate	Natural coarse aggregate	Fine aggregate
Absolute density in dry form (g/mm^3)		2.14	2.62	2.56
Absorption (%)		6.28	0.84	1.41
Abrasion (%)		21.1	14.6	-
Absolute volume (%)		57	59	58
Passage through a 0.08 mm sieve (%)		0.6	0.2	1.6
Alkaline Aggregate Reaction		Harmless	-	-
The amount of clay mass (%)		0.15	0.08	0.4
Stability (%)		4.9	2.4	3.5
Impurity content (%)	Organic impurity	Less than 1.0 (volume)	-	-
	Inorganic impurity	Less than 1.0 (weight)	-	-

The tensile strength, in compression, and splitting for the sulfur-melamine modifier-based concrete were explored and the results are indicated in Table.9. In this analyses, 7 types of sulfur-melamine modifier-based concrete related to the size aggregate were examined. It was found that

(i) The low size of aggregate in sulfur-melamine modifier-based concrete leads to more density, 2417 kg\m^3. The concrete density was decreased slowly with the size of aggregate.

(ii) The concrete example 5 is of more compressive strength, 84 MPa, and better splitting tensile strength, 6.3 MPa, than other samples. This concrete example prepared from the 25 mm size of aggregate.

Table 9. Tensile strength in compression and splitting for the sulfur-melamine modifier-based concrete.

Samples	Density (kg\m^3)	Compressive strength (MPa)	Splitting tensile strength (MPa)
№ 1	2417	49	-
№ 2	2389	52	-
№ 3	2374	69	-
№ 4	2365	74	5.2
№ 5	2383	84	6.3
№ 6	2348	81	4.4
№ 7	2392	73	4.6

The modulus of elasticity for the sulfur-melamine modifier-based concrete was also investigated and the obtained details are indicated in Table.10. The obtained results demonstrated the modulus of elasticity and deformation at maximum stress for the sulfur-melamine modifier-based concrete. It was found that the average deformation of studied concrete was (0.0030-0.0033), confirmed that the deformation performance of this concrete was better than the traditional concretes.

Table 10. Modulus of elasticity of the sulfur-melamine modifier-based concrete.

Samples	Deformation at maximum stress	E_{exp} (GPa)	E_{code} (GPa)	E_{exp}/E_{code} (%)
№ 1	-	-	-	-
№ 2	0.0052	21.3	34.2	62
№ 3	0.0024	48.7	39.4	124
№ 4	0.0035	35.4	41.0	86
№ 5	0.0031	36.4	43.1	84
№ 6	0.0027	35.6	42.8	83
№ 7	0.0024	37.3	40.1	93

Thermal expansion coefficient

The value in thermal expansion coefficient shows the concrete efficiency in the temperature changing conditions. The obtained results confirmed that the value in thermal expansion coefficient for sulfur-melamine modifier-based concrete was 17.2×10^{-6}\˚C. This value is very low and it is suggested that the selected sulfur concrete is more effective in the change of heat. It is also noted that the value of thermal expansion coefficient for sulfur-melamine modifier-based concrete is better than the traditional concretes, so that the thermal expansion coefficient of Portland cement concrete ranges from 10×10^{-6}\˚C to 13×10^{-6}\˚C.

Conclusion

In present research, the new type of concrete based on sulfur-melamine modification introduced and its various properties were studied. The new sulfur-melamine modifier was synthesized and its structure was confirmed by the IR spectroscopy and TG analysis. The surface morphology of this modification was studied by the SEM and EDS analyses. The new type of concrete was prepared based on the sulfur-melamine modification and various ingredients. The various properties of this concrete were identified, and the following main points were found:

(i) The large fillers and lower fillers at 36%:30% ratio were more efficient in the formation of concrete.

(ii) The addition of fly ash promoted the easy formability and strength. When 20% of modified sulfur-melamine was exchanged with fly ash, the targeted concrete was become of easy formability and highest strength.

(iii) The valence vibration of amino functional groups (attached melamine ring) was appeared at 3119-3467 cm^{-1}. In the 1432-1528 cm^{-1}, the valence vibrations of the C=N bonds were appeared. The polymer sulfur chains are built by the S-S bond formation. The 608-810 cm^{-1} IR signals were responsible for S-S bonds.

(iv)The sulfur-melamine modification thermic mass loss was one-step, and the mass loss processes of this modifier was endothermic processes.

(v)SEM results showed that the sulfur-melamine modifier a porous structure. It was found in EDS that the nitrogen atoms were accounted for 51.33% of total mass while the carbon was 30.94% of total mass.

(vi) The stability of sulfur-melamine modifier-based concrete was very high in the various aggressive solutions.

(vii) The water adsorption on the surface of sulfur-melamine modifier-based concrete was (0.1-0.37) % and coefficient of concrete against water adsorption was 0.83, indicating that the selected concrete is more stable in the aquatic and high humidity environments.

(viii) The stability coefficient of sulfur-melamine modifier-based concrete against freezing was near 1.0.

(ix) The low size of aggregate lead to more dense concrete, 2417 kg\m^3. The concrete density was decreased slowly with the increase in size of aggregate. The average deformation of studied concrete was (0.0030-0.0033), confirmed that the deformation performance of this concrete was better than the traditional concretes.

(x) The obtained results confirmed that the value in thermal expansion coefficient for sulfur-melamine modifier-based concrete was 17.2×10^{-6}\˚C.

Overall, the comprehensive studies in this research herald the suitability of sulfur-melamine as a modifier for concretes.

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Authors' Declaration

- Conflicts of Interest: None.
- We hereby confirm that all the Figures and Tables in the manuscript are ours. Furthermore, any Figures and images, that are not ours, have been included with the necessary permission for re-publication, which is attached to the manuscript.
- Ethical Clearance: The project was approved by the local ethical committee in University of Baghdad.

Authors' Contribution Statement

DS: Writing – Original Draft. KT: Reviewing and editing paper. NA: Reviewing and editing paper. BL: Reviewing and editing paper. KB: Software, Validation. EB: Writing – Original Draft, Conceptualization, Investigation, Visualisation. AHB: Reviewing and editing paper.

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تحضير نوع جديد من الخرسانة بواسطة تحوير الكبريت والميلامين

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الخلاصة

في هذا البحث تم تحضير نوع جديد من الخرسانة يعتمد على تحوير الكبريت والميلامين ودراسة خصائصها المختلفة. حضر هذا النوع الجديد من الخرسانة بناءً على تعديل الكبريت والميلامين والمكونات المختلفة. تم اثبات هذه التعديلات من خلال التحليل الطيفي للأشعة تحت الحمراء وتحليل TG. تمت دراسة التشكل السطحي الناتج عن هذا التعديل من خلال تحليل SEM وEDS وتم دراسة نسب المكونات في الخواص الخرسانية والكيميائية والفيزيائية الناتجة عن تعديل الكبريت والميلامين، كما تم دراسة المقاومة الكيميائية والتآكل للخرسانة، وثبات الخرسانة ضد امتصاص الماء، وثبات الخرسانة ضد التجمد، والخصائص الفيزيائية والميكانيكية والمتانة، ومعامل المرونة، والحرارية ومعامل التمدد للخرسانة الكبريتية المدروسة. أكدت نتائج الأشعة تحت الحمراء المجموعات الوظيفية الأمينية (حلقة الميلامين المرفقة) وتشكيل سلاسل متعدد الكبريت. كانت خسارة الكتلة الحرارية لتعديل الكبريت والميلامين خطوة واحدة. كانت عمليات فقد الكتلة للمنتج المعدل عمليات ماصة للحرارة. كشفت نتائج SEM التي تم الحصول عليها أن تعديل الكبريت والميلامين يؤدي إلى بنية مسامية أكثر ، بدون أي أشكال بلورية. أظهر تحليل EDS أن ذرات النيتروجين شكلت 51.33٪ من الكتلة الكلية بينما كان الكربون 30.94٪ من الكتلة الكلية. كان ثبات الخرسانة المعدلة الكبريت والميلامين عاليًا جدًا في المحاليل القوية المختلفة. كان الحجم المنخفض للخرسانة القائمة على الركام أكثر كثافة \، 2417 كجم / م ^{3}. انخفضت كثافة الخرسانة ببطء مع زيادة حجم الركام. كان معدل التشوه للخرسانة المعدلة 0.0033-0.0030 مما يؤكد على ان فعالية الخرسانة المعدلة أفضل من الخرسانة التقليدية. كما أكدت النتائج المتحصل عليها أن قيمة معامل التمدد الحراري للخرسانة المعدلة من الكبريت والميلامين كانت 17.2×10^{-6}\°C درجة مئوية.

الكلمات المفتاحية: الكبريت، الميلامين، الخرسانة الكبريتية، مرونة، معامل التمدد الحراري، التعديل.