ABSTRACT: After oil and gas well drilling, they should be cased and cemented to ensure the stability of the well bore and to isolate the trouble zones. To achieve these jobs, several additives are incorporated into the cement slurry to improve the cement matrix durability, especially at temperatures above 230 F. The tire waste material is an industrial waste that comes from automobile tires. The purpose of this work is to investigate the prospect of utilizing tire waste in oil-well cement under high-temperature and high-pressure conditions of 292 F and 3000 psi. Three cement samples with different concentrations of the tire waste material were prepared. The effects of tire waste on the cement rheological properties, elastic and failure parameters, and permeability were examined. The results showed that adding 0.3% by weight of cement (BWOC) of the tire waste material considerably improved the cement to the cement slurry and cement matrix properties, and it decreased the cement plastic viscosity by 53.1% and increased its yield point by 142.4% compared to the base cement. The cement samples with 0.3% BWOC of tire waste have Young’s modulus which is 10.8% less than that of the base cement and Poisson’s ratio of 14.3% greater than that of the base cement. By incorporating 0.3% of the tire waste, both compressive and tensile strengths of the cement increased by 48.3 and 11.7%, respectively, compared with those of the base cement. The cement permeability was decreased by 66.0% after adding 0.3% of the tire waste. Besides the improvement in the properties of cement, the use of the tire waste material has other economical and environmental advantages because these are very cheap materials dominant in our life.

1. INTRODUCTION

Oil-well cement is one of the most important materials in drilling operations.1 After drilling the well, the cement is pumped into the annulus between the wall of the formations and casing.2 The cement has many functions that can be divided into primary and other functions. Primary functions are isolating formations with high porosity from having cross flow with different zones, carrying the casing weight, and supporting any applied load.3 Other functions are preventing unwanted downhole fluids from being produced, protecting the casing from having corrosion, and restraining abnormal pore pressure.4 According to Nelson,5 the significance of an appropriate cement slurry depends on the point that without proper isolation of trouble zones, the well might never achieve its maximum potential of production.

The design of a cement slurry usually includes several additives and materials, and these should be compatible with others and able to perform different functions to provide cement matrices of high quality.6 For instance, silica flour is used to enhance the strength and maintain lower permeability,8 weighting materials are used to increase the density,9 accelerators are used to reduce the setting time,10 retarders are used to delay the setting time, extenders are used to decrease the density,11 dispersants are used to reduce the viscosity, fluid loss agents are used to control the leakage of the aqueous phase of the cement, and defoamers are used to prevent foaming.12

An appropriate laboratory experiment is required to optimize the cement formulation to improve the cement properties.13 Recently, many researchers examined the impacts of various materials on the cement properties, for example, olive waste,14 laponite,15 nanoclay,16,17 cellulose nanofibers,18 granite sludge,19 polypropelene fibers,20,21 metakaolin,22 rice husk ash,23 silica flour,24 silicon carbide powder,25 iron ore tailings,26 and sugarcane biomass waste.27

The application of waste materials in oil-well cement is extremely encouraged from the environmental perspective because industrial wastes can lead to many issues to the environment and human health when disposed of in an inappropriate way.28−30 Tire waste discarding leads to biodiversity reduction; also, tires contain soluble and poisonous elements.31 When tires begin to torch because of incidental
reasons, high temperature occurs and harmful exhausts are created, and the high temperature makes tires to melt, so oil will be produced and pollute soil and water.32 Moreover, the transportation and discarding of these wastes require considerable costs. Therefore, researchers have looked for choices to join these deposits in other industrial operations, thus decreasing costs and the ecological effects produced by the improper waste removal.

1.1. Tire Waste Material and Its Applications. Tire waste is a reused material obtained from a huge quantity of scrapped vehicle tires. Tire waste is produced by two main processes, that is, ambient and cryogenic.33 The ambient method provides a tire waste material of a comparatively large particle size, where the mechanical processes to cut and grind the tire material to certain sizes are under ambient temperatures. The size of ambient tire waste ranges from very fine particles (less than 0.6 mm) to coarse particles (3−13 mm). Cryogenic methods start with around 50 mm shredded scrap tires which are placed in liquid nitrogen, to cool the material under temperatures less than −112 F, causing the material to be brittle and easily crushed and ground to the required sizes of less than 0.6 mm.34 After the ambient and cryogenic processes, the separation process starts to remove the contaminants from the materials such as fibers and steel.

There are many applications of tire waste in several industries. It is suggested to be used in concrete structures found in the regions of serious earthquake risks and severe railway sleepers. It is also applied to construct the barriers of noise reduction.35 Tire waste materials have been utilized as a secondary material in the pavement industry to decrease pavement cracking and increase the thermal stability.36 Studies also showed that the performance of concrete has high dependency on the aggregation of tire waste.59 The use of tire waste in concrete cement showed that tire waste can enhance cement deformation ability and mechanical properties.40−43

In the petroleum industry, tire waste was used by Al Awad and Fattah.44 They tested a good fracture seal material made of shredded waste car tires in the lab to see its ability to plug a fractured core sample under high-pressure and high-temperature conditions. Agapiou et al.34 investigated the impacts of three types of waste tires on the mechanical properties of cement. The three types are tire fillings, tire rubber crumbs, and ground rubber tires. Their results showed that tire fillings and tire rubber crumbs exhibit similar compressive strength and tensile strength. However, the ground rubber tire has the highest compressive strength and tensile strength.

Xiaowei et al.35 used a modified crumb tire waste material to enhance the adhesion and the mechanical properties of cement. They used several techniques to evaluate the surface properties of the crumb tire waste and the cement. Li and Guo61 studied the impact of tire powder in oil-well cement and revealed that the tire waste increases the elastic deformation capability of the cement. Tire waste is modified by the plasma technology with less temperature and reduces the elastic modulus, which leads to the enhancement of elastic and plastic deformation capability.37,48 The microstructure of cement containing tire elastic particles was examined by Liu et al.49 and they concluded that the cement deformation capability is improved, and the elastic modulus is decreased.

The purpose of this work is to assess the possibility of using the tire waste in oil-well cement under a high temperature of 292 F and a high pressure of 3000 psi. The effect of using different concentrations of the tire waste material on the cement rheological properties (yield point and plastic viscosity), elastic properties (dynamic Young’s modulus and dynamic Poisson’s ratio), failure parameters (compressive and tensile strength), and petrophysical properties (permeability) was evaluated.

2. MATERIALS AND METHODOLOGY

2.1. Materials. Three cement slurries were formulated with the composition of Saudi Class G cement, silica flour, a weighting material, a fluid loss controller, a dispersant, a retarder, an expander, water, a defoamer, and the tire waste material. These samples were prepared following the American Petroleum Institute (API) standards.50−52 The cement slurries were prepared with a water-to-cement ratio of 0.44. Saudi Class G cement and all other additives used in this study are provided by a service company.

Table 1 lists the concentration of the different additives used to make the three slurries prepared in this work; as indicated in this table, the disparity between the three cement slurries is the tire waste material’s concentration, while all remaining additives have the same amount in all the slurries. The first slurry (TWM0) is the base slurry which has no tire material, the second slurry (TWM1) contains 0.1% by weight of cement (BWOC) of the tire waste material, and the third slurry (TWM3) has 0.3% BWOC of the tire waste material.

The tire waste material used in this study is an industrial waste material that comes from the automobile tires. It is extremely encouraged from the environmental perspective to find a use of these wastes because it could lead to many issues to the environment and human health when disposed in an inappropriate way. The tire waste material has several applications in the concrete industry and some applications in oil and gas industries. The tire waste material is mainly the rubber layer form the tire body; this rubber material was extracted from the used (obsolete) tire; as shown in Figure 1, the used tires were first processed to remove the metallic components and keep only the rubber material, and this rubber was then cut into large particles, which were then shredded into smaller particles, which were finally crushed to make rubber powder of small particle sizes, which was then added to the cement material to improve the elastic characteristics of the cement matrix.

Table 2 compares the elemental composition of the tire waste material and Saudi Class G cement as characterized by X-ray fluorescence (XRF). The XRF results indicate that the tire waste material is mainly composed of Zn (41.84%) and it has a low Ca concentration of 15.51% compared with 72.1% of Ca in Saudi Class G cement.

![Tire Waste Material Composition](https://dx.doi.org/10.1021/acsomega.0c04270)
2.2. Methodology. After preparing the cement slurries following the standards of API\textsuperscript{10} and API\textsuperscript{51} some of the slurries were used for the measurements of the cement slurry rheological properties of plastic viscosity and yield point, while the remaining were poured into cylindrical and cubical molds to prepare cement samples with different dimensions and cured for 24 h at 3000 psi and 292 F using a high-pressure and high-temperature curing chamber. These samples were used for the evaluation of the cement elastic parameters of Young’s modulus and Poisson’s ratio and cement failure parameters of compressive and tensile strength and permeability measurements. The following sections explain the testing procedures and the specification of the samples prepared to evaluate the different cement properties.

2.2.1. Rheological Property Measurement. The effect of incorporating the tire waste material into the cement slurry rheological characteristics of yield point and plastic viscosity was evaluated for all the cement slurries under study at 194 F and atmospheric pressure. During the rheological property evaluation, the cement slurries were subjected to shear forces at rates of 3, 6, 100, 200, and 300 rpm in the ascending order and then in the descending order and the corresponding shear stresses were measured and recorded. The average shear stress at every shear rate value was then calculated as the arithmetic average of the two readings. Then, these values were considered for the calculations of the yield point and plastic viscosity.

2.2.2. Elastic Parameter Measurement. The effects of the tire waste material on the elastic properties of the cement of Young’s modulus and Poisson’s ratio were also studied for all cement samples after curing for 24 h at 292 F and 3000 psi. For this purpose, cylindrical cement samples with a diameter of 3.81 cm and a length of 7.62 cm were prepared. Young’s modulus and Poisson’s ratio of the samples were calculated as a function of the ultrasonic velocities (i.e., P-waves and S-waves) which were measured using the sonic mode of the scratch testing machine.

2.2.3. Failure Parameter Measurement. The effect of the tire waste material on two failure parameters of the cement, namely, the compressive and tensile strengths was evaluated for the cement samples after curing for 24 h at 292 F and 3000 psi. For the compressive strength measurements, for each cement formulation, three cubical samples with edges of 5.08 cm were prepared according to the American Society for Testing and Material (ASTM) standard.\textsuperscript{52} The compressive

---

Table 2. Composition of Saudi Class G Cement and Laponite

| element | Saudi Class G cement | tire waste material |
|---------|---------------------|---------------------|
| Na      | 0.00                | 2.99                |
| Mg      | 1.33                | 1.91                |
| Al      | 2.37                | 2.28                |
| Si      | 12.1                | 9.96                |
| S       | 2.43                | 11.35               |
| Cl      | 0.00                | 1.35                |
| K       | 0.00                | 2.18                |
| Ca      | 72.1                | 15.51               |
| Ti      | 0.39                | 0.33                |
| Mn      | 0.05                | 0.11                |
| Fe      | 9.08                | 9.99                |
| Zn      | 0.00                | 41.84               |
| Sr      | 0.15                | 0.20                |

---

Figure 1. Steps of processing the old tires to make the rubber powder to be mixed with Saudi Class G oil-well cement.
strength of every sample was evaluated at room temperature using the crushing machine. The compressive strength measurement for every cement formulation was repeated three times using different specimens every time, and then, the compressive strength for every cement sample was calculated as the average of the three measurements. The results of these measurements showed good consistency of the three compressive strengths for every cement formulation.

The cement tensile strength of every cement formulation considered in this study was evaluated using three cement cylindrical samples with a diameter of 3.81 cm and a length of 2.29 cm using the indirect Brazilian testing procedure as explained earlier by Mahmoud et al.\textsuperscript{53} and Mahmoud and Elkatatny.\textsuperscript{54} Then, the tensile strength for every cement formulation was calculated as the average strength of the three measurements. The results of these measurements showed good consistency of the three tensile strengths for every cement formulation.

2.2.4. Permeability Measurement. The permeability was measured for all cement samples after curing for 24 h at 292 F and 3000 psi on cylindrical samples with a diameter of 3.81 cm and a length of 1.52 cm following the procedures explained by Sanjuán and Muñoz-Martíalay\textsuperscript{55} through the use of the Hagen–Poiseuille law, which is commonly used for estimating the porous media permeability using a compressible fluid (mostly a gas) injected under steady-state and laminar flow conditions.\textsuperscript{56} Nitrogen gas was used for permeability measurement; it was injected through the cement cylindrical samples at 1200 psi while applying a backpressure of 500 psi. Then, the permeability was calculated as a function of the nitrogen flow rate and viscosity, pressure drop, and sample dimensions.

3. RESULTS AND DISCUSSION

3.1. Rheological Properties. The influence of the tire waste material on the rheological properties of the cement is shown in Figure 2, which shows the effect of changing the concentration of the tire waste material on the plastic viscosity and yield point of the three cement slurries considered in this study.

As shown in Figure 2, the plastic viscosity of the base slurry (TWM0), which has no tire waste material, was very high (352 cP), and incorporating 0.1% of the tire waste material into sample TWM1 reduced the cement plastic viscosity to 258 cP with a reduction of 26.7% compared with that of the base sample (TWM0). Sample TWM3, which contains 0.3% BWOC of the tire waste material, decreased the plastic viscosity by 53.1% compared with sample TWM0 to 165 cP. In this part of the study, a cement slurry with 0.5% of the tire waste material was also prepared for rheology measurements, but the formed slurry was very thick, indicating a significant increase in the slurry plastic viscosity, so it is not recommended to use the tire waste material with a concentration of greater than 0.3%; therefore, the maximum concentration of the tire waste material used throughout this study was 0.3% BWOC.

The reduction in the plastic viscosity is an important characteristic for the cement slurry because it could significantly assist the cement to be pumped easily downward through the wellbore and then up through wellbore annular space; this is because of the reduction in the flow resistance;\textsuperscript{56} therefore, addition of the tire waste material is expected to reduce the flow resistance of the cement slurry and reduce the required pumping power.

The results of the change in the yield point of the cement slurries due to addition of the tire waste material are also shown in Figure 2. Overall, these results show that there is an enhancement in the yield point when the tire waste material is added to the cement slurry. The base cement sample (TWM0) has a yield point of 66 lb/100 ft\textsuperscript{2}. Adding 0.1 and 0.3% BWOC of the tire waste material into samples TWM1 and TWM3 increased the yield point to 108 and 160 lb/100 ft\textsuperscript{2} with a 63.6 and 142.4% increase compared with the base cement, respectively.

The increase in the yield point is another critical characteristic of the cement slurry which indicates the improvement in the carrying ability of the cement slurry when the cement pumping is stopped for any reason.\textsuperscript{56} The results of this study indicate that incorporating the tire waste material could improve the carrying ability of the cement slurry.

3.2. Elastic Parameters. The elastic properties of Young’s modulus and Poisson’s ratio were also studied for all cement samples considered in this study, as shown in Figure 3. For the change in Young’s modulus as indicated in Figure 3, incorporating the tire waste material into the cement slurry shows a decrease in Young’s modulus. The base sample (TWM0) has Young’s modulus of 23.1 GPa. Adding 0.1% of the tire waste material into sample TWM1 reduced Young’s modulus to 21.9 GPa with a reduction of 5.2% compared to

![Figure 2. Plastic viscosity and yield point of all cement samples considered in this study as evaluated at 194 F and atmospheric pressure.](image)

![Figure 3. Young’s modulus and Poisson’s ratio of all cement samples considered in this study after curing for 24 h at 292 F and 3000 psi.](image)
that of sample TWM0, while sample TWM3, which contains 0.3% of the tire waste material, has Young’s modulus of 20.6 GPa, which is 10.8% less than that for the base sample. These results indicate that using the tire waste material reduced the cement matrix Young’s modulus; therefore, it helps in developing a cement matrix which is more stable under shear deformation.

The change in Poisson’s ratio is also shown in Figure 3, which indicates that incorporating the tire waste material into the cement slurry improved its Poisson’s ratio. The base sample (TWM0) has Poisson’s ratio of 0.28. Samples TWM1 and TWM3 have Poisson’s ratios of 0.31 and 0.32, which are 10.7 and 14.3% greater than Poisson’s ratio of the base cement, respectively. Increasing Poisson’s ratio implies that the cement became incompressible, and this will enhance the cement expansion around the casing. Therefore, the tire waste material provides the cement with higher expansion.

3.3. Failure Parameters. The impact of adding the tire waste material on the cement failure parameters of the compressive and tensile strengths was evaluated for the different cement samples considered in this study. Figure 4 illustrates the compressive strength for the three cement samples. The results showed that the compressive strength for sample TWM0, which has no tire waste material (0% TWM), was 46.8 MPa. It is clear that the tire waste has a positive impact on the cement compressive strength, where adding 0.1% of tire waste into sample TWM1 improved the compressive strength to 55.0 MPa with an increase of 17.5% compared to that of sample TWM0, and increasing the tire waste material concentration to 0.3% BWOC for sample TWM3 increased the cement matrix compressive strength to 69.4 MPa with an increase of 48.3% compared with that of sample TWM0. This improvement in the compressive strength will help the cement to provide more support to the casing and wellbore. Also, 0.5% of the tire waste material improved the strength to 72.2 MPa.

In addition, the tensile strengths for the three cement samples were measured, as shown in Figure 4. The base cement sample (TWM0) has a tensile strength of 1.97 MPa, while samples TWM1 and TWM3 have tensile strengths of 2.05 and 2.20 MPa with an increase in the tensile strength of 4.1 and 11.7% compared with those of sample TWM0, respectively. These improvements will help the cement to withstand the tension forces and to carry the weight of the casing, especially in the deviated sections of the well.

3.4. Permeability. Figure 5 compares the change in the cement permeability for all cement samples prepared in this study. As shown in this figure, the cement permeability was decreased by increasing the tire waste material concentration. The base cement sample (TWM0) permeability was 0.094 mD. Adding 0.1% of the tire waste material into sample TWM1 decreases the matrix permeability to 0.046 mD to provide a reduction in the permeability by 51.1% compared to sample TWM0, and increasing the tire waste material concentration to 0.3% in sample TWM3 decreased the permeability to 0.032 mD with a decrease of 66.0% compared with that of the base sample (TWM0). The reduction in the cement permeability because of incorporation of the tire waste material will significantly help the cement matrix to provide excellent zonal isolation.

4. CONCLUSIONS

Cement slurries with 0, 0.1, and 0.3% BWOC of the tire waste material were prepared in this study and cured at 292 F and 3000 psi to evaluate the use of the tire waste material to improve the cement rheological properties, elastic and failure parameters, and permeability. The results showed that the cement slurry mixed with the waste has better properties than the base slurry, and the following points are concluded out of this study:

- The optimum concentration of the tire waste material is 0.3% BWOC, and beyond this concentration, the plastic viscosity of the slurry significantly increased.
- Compared to the base cement, the plastic viscosity of the cement was decreased by 53.1% and its yield point increased by 142.4% when 0.3% BWOC of tire waste is added.
- The cement samples with 0.3% BWOC of tire waste have Young’s modulus which is 10.8% less than that of the base cement and Poisson’s ratio 14.3% greater than that of the base cement.
- Addition of 0.3% BWOC of the tire waste increased both the compressive and tensile strengths of the cement by 48.3 and 11.7%, respectively, compared with those of the base cement.
The cement permeability was decreased by 66.0% after adding 0.3% of the tire waste.

AUTHOR INFORMATION

Corresponding Author
Salaheldin Elkatatny — College of Petroleum Engineering and Geosciences, King Fahd University of Petroleum & Minerals, 31261 Dhahran, Saudi Arabia
  orcid.org/0000-0002-7209-3715; Email: elkatatny@kfupm.edus

Authors
Abdulmalek Ahmed — College of Petroleum Engineering and Geosciences, King Fahd University of Petroleum & Minerals, 31261 Dhahran, Saudi Arabia
Ahmed Abdulhamid Mahmoud — College of Petroleum Engineering and Geosciences, King Fahd University of Petroleum & Minerals, 31261 Dhahran, Saudi Arabia
Rahul Gajbiye — College of Petroleum Engineering and Geosciences, King Fahd University of Petroleum & Minerals, 31261 Dhahran, Saudi Arabia
  orcid.org/0000-0003-3906-5453

Complete contact information is available at: https://pubs.acs.org/10.1021/acsomega.0c04270

Notes
The authors declare no competing financial interest.

ACKNOWLEDGMENTS

The authors would like to acknowledge the College of Petroleum Engineering and Geosciences at King Fahd University of Petroleum and Minerals for the support and permission to publish this work.

REFERENCES

(1) El-Gamal, S. M. A.; Hashem, F. S.; Amin, M. S. Influence of carbon nanotubes, nanosilica and nanometakaolin on some morphological-mechanical properties of oil well cement pastes subjected to elevated water curing temperature and regular room air curing temperature. Constr. Build. Mater. 2017, 146, 531−546.
(2) Ahmed, R. M.; Takachi, N. E.; Khan, U. M.; Taoutoua, S.; James, S.; Saasen, A.; Goday, R. Rheology of foamed cement. Concr. Res. 2009, 39, 353−361.
(3) Rodrigues, E. C.; de Andrade Silva, F.; de Miranda, C. R.; de Sá Cavalcante, G. M.; de Souza Mendes, P. R. An appraisal of procedures to determine the flow curve of cement slurries. J. Pet. Sci. Eng. 2017, 159, 617−623.
(4) Mahmoud, A. A.; Elkatatny, S. Mitigating CO2 Reaction with Hydrated Oil Well Cement under Geologic Carbon Sequestration Using Nanoclay Particles. J. Nat. Gas Sci. Eng. 2019, 68, 102902.
(5) Nelson, E. B. Well Cementing. Elsevier: New York, 1990.
(6) Kremieniewski, M.; Rzepek, M. Correlation of permeability and parameters describing the structure of hardened cement slurries used to seal boreholes in the area of the Pomeranian Basin. Nafta Gaz. 2015, 10, 737.
(7) Kremieniewski, M.; Rzepek, M. The causes and effects of gas flow in the cemented annular space of borehole and methods to prevent this phenomenon. Nafta Gaz. 2016, 72, 722.
(8) Taylor, H. F. W. Cement Chemistry, 2nd ed; Thomas Telford Publishing: London, 1997.
(9) Ahmed, A.; Mahmoud, A. A.; Elkatatny, S.; Chen, W. The Effect of Weighting Materials on Oil-Well Cement Properties While Drilling Deep Wells. Sustainability 2019, 11, 6776.
(10) Kremieniewski, M. Recipe of Lightweight Slurry with High Early Strength of the Resultant Cement Sheath. Energies 2020, 13, 1583.
(11) Kremieniewski, M. Improvement of the early mechanical strength of cement sheath formed from lightweight cement slurry. Nafta Gaz. 2018, 74, 606.
(12) Eric, B.-B.; Joel, F.; Grace, O. Oil Well Cement Additives: A Review of the Common Types. Oil Gas Res. 2016, 2, 112.
(13) Calvert, D. G.; Smith, D. K. API oil well cementing practices. J. Pet. Technol. 1990, 42, 1364−1373.
(14) Mahmoud, A. A.; Elkatatny, S. Improved durability of Saudi Class G oil-well cement sheath in CO2 rich environments using olive waste. Constr. Build. Mater. 2020, 262, 120623.
(15) Elkatatny, S. Development of a Homogenous Cement Slurry Using Synthetic Modified Phyllosilicate while Cementing HPHT Wells. Sustainability 2019, 11, 232.
(16) Mahmoud, A. A.; Elkatatny, S.; Mahmoud, M. Improving Class G Cement Carbonation Resistance Using Nanoclay Particles for Geologic Carbon Sequestration Applications. Proceedings of the 2018 Abu Dhabi International Petroleum Exhibition & Conference, Abu Dhabi, UAE, November 12−15, 2018.
(17) Mahmoud, A. A.; Elkatatny, S. Effect of the Temperature on the Strength of Nanoalloy-Based Cement under Geologic Carbon Sequestration. Proceedings of the 2019 AADTE National Technical Conference and Exhibition, Denver, Colorado, USA, April 9−10, 2019.
(18) Sun, X.; Wu, Q.; Zhang, J.; Qing, Y.; Wu, Y.; Lee, S. Rheology, curing temperature and mechanical performance of oil well cement: Combined effect of cellulose nanofibers and graphene nano-platelets. Mater. Des. 2017, 114, 92−101.
(19) Medina, G.; Sáez del Bosque, I. F.; Frias, M.; Sánchez de Rojas, M. I.; Medina, C. Energy performance and calorimetric behaviour of cements bearing granite sludge. Powder Technol. 2019, 356, 517−527.
(20) Elkatatny, S.; Gajbiye, R.; Ahmed, A.; Mahmoud, A. A. Enhancing the cement quality using polypropylene fiber. J. Pet. Explor. Prod. Technol. 2019, 10, 1097−1107.
(21) Mahmoud, A. A.; Elkatatny, S. Synthetic Polypropylene Fiber Content Influence on Cement Strength at High-Temperature Conditions. Proceedings of the 53rd US Rock Mechanics/Geomechanics Symposium held in New York, USA, June 23−26, 2019.
(22) Bu, Y.; Du, J.; Guo, S.; Liu, H.; Huang, C. Properties of oil well cement with high dosage of metakaolin. Constr. Build. Mater. 2016, 112, 39−49.
(23) Soares, L. W. O.; Braga, R. M.; Freitas, J. C. O.; Ventura, R. A.; Pereira, D. S. S.; Melo, D. M. A. The effect of rice husk ash as pozolana in addition to cement Portland class G for oil well cementing. J. Pet. Sci. Eng. 2015, 131, 80−85.
(24) Mahmoud, A. A.; Elkatatny, S. The Effect of Silica Content on the Changes in the Mechanical Properties of Class G Cement at High Temperature from Slurry to Set. Proceedings of the 53rd US Rock Mechanics/Geomechanics Symposium held in New York, USA, June 23–26 2019.
(25) Jeon, I. K.; Qudoos, A.; Jakhani, S. H.; Kim, H. G.; Ryoo, J.-S. Investigation of sulfuric acid attack upon cement mortars containing silicon carbide powder. Powder Technol. 2020, 359, 181−189.
(26) Yao, G.; Wang, Q.; Wang, Z.; Wang, J.; Lyu, X. Activation of hydration properties of iron ore tailings and their application as supplementary cementitious materials in cement. Powder Technol. 2020, 360, 863−871.
(27) Anjos, M. A. S.; Martinelli, A. E.; Melo, D. M. A.; Renovato, T.; Souza, P. D. P.; Freitas, J. C. Hydration of oil well cement containing sugarcane biomass waste as a function of curing temperature and pressure. J. Pet. Sci. Eng. 2013, 109, 291−297.
(28) Singh, S.; Nagar, R.; Agrawal, V. Performance of granite cutting waste concrete under adverse exposure conditions. J. Clean. Prod. 2016, 127, 172−182.
(29) Thomas, B. S.; Gupta, R. C. A comprehensive review on the applications of waste tire rubber in cement concrete. Renew. Sustain. Energy Rev. 2016, 54, 1323−1333.
(30) Ahmad, M. M.; Ahmad, F.; Azmi, M.; Mohd Zahid, M. Z. A.; Ab Manaf, M. B. H.; Isa, N. F.; Sofri, N. Z.; Azizi Azizan, M.; Muhammad, K.; Sofri, L. A. Properties of Cement-Based Material
Consisting Shredded Rubber as Drainage Material. Appl. Mech. Mater. 2015, 815, 84−88.
(31) Thomas, B. S.; Gupta, R. C.; Mehra, P.; Kumar, S. Performance of high strength rubberized concrete in aggressive environment. Constr. Build. Mater. 2015, 83, 320−326.
(32) Gesoğlu, M.; Guneysu, E. Permeability properties of self-compacting rubberized concretes. Constr. Build. Mater. 2011, 25, 3319−3326.
(33) Blumenthal, M. H. Producing Ground Scrap Tire Rubber: A Comparison Between Ambient and Cryogenic Technologies. Proceedings of the 17th Biennial Waste Processing Conference, Atlantic City, 3 March−3 April, 1996.
(34) Agapiou, K.; Gamwell, C. R.; Sodhi, T. S. Influence of Recycled Rubber Tire Morphology on the Mechanical Properties of Well Cements. Proceedings of the American Rock Mechanics Association, 2016, https://www.onepetro.org/conference-paper/ARMA-2016-321.
(35) Sofi, A. Effect of waste tyre rubber on mechanical and durability properties of concrete − A review. Ain Shams Eng. J. 2018, 9, 2691−2700.
(36) Presti, D. L. Recycled tyre rubber modified bitumens for road asphalt mixtures: A literature review. Constr. Build. Mater. 2013, 49, 863−881.
(37) Terrel, R. L.; Walter, J. L. Modified asphalt pavement materials − the European experience (with discussion). Proceedings of the Association of Asphalt Paving Technologists, 1986, https://trid.trb.org/view/575987.
(38) Renshaw, R. H.; Hoffmann, P.; Potgieter, C. J. Bitumen rubber asphalt in South Africa and experience in China, 2007. Retrieved from https://repository.up.ac.za/handle/2263/5926 (accessed February 22, 2020).
(39) Pacheco-Torgal, F.; Ding, Y.; Jalali, S. A Properties and durability of concrete containing polymeric wastes (tyre rubber and polyethylene terephthalate bottles): An overview. Constr. Build. Mater. 2012, 30, 714−724.
(40) Elghazouli, A. Y.; Bompa, D. V.; Xu, B.; Ruiz-Teran, A. M.; Stafford, P. J. Performance of rubberised reinforced concrete members under cyclic loading. Eng. Struct. 2018, 166, 526−545.
(41) Thomas, B. S.; Gupta, R. C. A comprehensive review on the applications of waste tire rubber in cement concrete. Renew. Sustain. Energy Rev. 2016, 54, 1323−1333.
(42) Benazzouk, A.; Douzane, O.; Mezreb, K.; Quénéudec, M. Physico-mechanical properties of aerated cement composites containing shredded rubber waste. Cem. Concr. Compos. 2006, 28, 650−657.
(43) Thomas, B. S.; Gupta, R. C. Long term behaviour of cement concrete containing discarded tire rubber. J. Clean. Prod. 2015, 102, 78−87.
(44) Al Awad, M. N.; Fattah, F. Utilization of Shredded Waste Car Tyres as a Fracture Seal Material (FSM) in Oil and Gas Drilling Operations. J. Pet. Environ. Biotechnol. 2017, 8, 21.
(45) Xiaowei, C.; Sheng, H.; Xiaoyang, G.; Wenhui, D. Crumb waste tire rubber surface modification by plasma polymerization of ethanol and its application on oil-well cement. Appl. Surf. Sci. 2017, 409, 325−342.
(46) Li, Z. Y.; Guo, X. Y. Effects of rubber powder on dynamics properties of oil cement stone. Pet. Drill. Tech. 2008, 36, 52−55.
(47) Cheng, X.; Fan, H.; Huang, S.; Li, Z.; Guo, X. Improvement of the properties of plasma-modified ground tire rubber-filled cement paste. Appl. Polym. Sci. 2012, 126, 1837−1843.
(48) Long, D.; Cheng, X. W.; Shi, Y.; Huang, L.; Liu, K. Q.; Li, Z. Y.; Guo, X. Y. Properties of oil well cement-based composite with minute rubber powder. Build. Chin. Ceram. Soc. 2015, 54, 2629−2633.
(49) Liu, R. G.; Zhou, S. M.; Tao, Q.; Yan, P. Microstructure of flexible oil-well cement stone mixed with latex and elastic particle. J. Chin. Ceram. Soc. 2015, 43, 1475−1482.
(50) Worldwide Cementing Practices; American Petroleum Institute: Dallas, Texas, USA, 1991.