Original Research

Analysis of Applicability of Modified Drilling Waste for Filling out Annular Space in Horizontal Directional Drilling

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Abstract

The construction of linear underground installations with horizontal directional drilling (HDD) technology creates certain problems, i.e. the generation of large quantities of drilling cuttings – a problem that has not yet been fully solved. Moreover, the annular space formed between the wall of the borehole and the driven pipe is not additionally filled out. Only drilling mud and small quantities of cuttings are left there, which may later result in subsidence and collapsing of the ground over the installed pipeline.

The authors present an innovative method for disposing of drilling wastes, i.e. treating the wastes and using them as mineral additives of industrial Puzzolan character to cement slurries for filling out the annular space in horizontal directional drilling.

Keywords: horizontal directional drilling (HDD), borehole, drilling wastes, cement slurry

Introduction

When designing works using trenchless technology and drilling mud, the extensive production of drilling waste is a really important issue. The waste mainly appears in the form of used drilling mud and cuttings. Their quantities are considerable and mainly depend on the assumed drilling technology, type of drilling mud, geologic conditions, and the length and diameter of the installed pipeline. For example, when installing a steel pipe 508 mm in diameter with horizontal directional drilling (HDD), about 0.45 m^3 of cuttings are produced and about 1.5÷2.0 m^3 of drilling mud are used for each running meter of installation [1-3].

In the present situation, when waste management regulations become more and more restrictive, attempts are made to minimize the production of waste. Unluckily, practically no environmentally-friendly methods of drilling waste disposal exist, therefore in most cases the cuttings are just stored [2-4]. Waste disposal through storing is the least environmentally safe and is becoming more expensive because of the growing environmental fees and costs. Companies using HDD technologies are obliged to consider all accessible methods of reducing the drilling mud excess, and selecting the most economically and environmentally plausible procedures for its utilization [5, 6].

Selected Methods of Drilling Mud and Wastes Utilization

Practical experience reveals that the most common solution lies in leaving out drilling mud in the area of wastelands or disposing of dry, dehydrated mass in a utilization place as arranged for with an investor or the respective organ of local administration.

The basic step toward effective management of drilling mud should lie in minimization of its volume. This can be

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achieved through specialist treatment equipment (vibration sieves, hydrocyclones, centrifuge machines, flocculation stations). Treated drilling mud becomes fully usable again and can be re-used in the drilling process. Separated cuttings are wet and have drilling mud admixture, therefore have to undergo dewatering processes in the filter press. Dehydration lowers the cost of utilization as liquid waste is eliminated and total mass of waste reduced [7-11].

Stabilization is an alternative use for the used drilling mud. This process lies in mixing the mud with a reagent, initiating a setting process. As a result, solid blocks are formed. Among the setting agents are fly ash, blast furnace slag, cement furnace dust, and various clayey minerals [8-10].

The results of tests on the usability of modified waste as a mineral additive to cement slurries are discussed in this paper. Modified wastes can be re-used for filling out empty spaces in directional boreholes, which should prevent subsidence and collapsing of the ground over the pipeline.

Accordingly, rheological, filtration, and strength parameters were worked out for the analyzed cement slurries. Rheological models were also presented for specific slurries.

Experimental Procedures

Laboratory investigations were aimed at determining the influence of thermally modified drilling waste on technological, rheological, and strength parameters of cement slurries based on blast-furnace cement CEM III/A 32.5 – LH/HSR/NA from Górażdże Cement S.A., to be later used for filling out annular spaces in HDD. Blast-furnace cement was made from a blend of ordinary Portland cement, and crushed slag from a blast furnace.

Laboratory analyses covered:

- measurement of technological parameters of fresh cement slurries (density, spillability, filtration, rheology) [11]
- beginning and end of bonding of slurries measured with Vicat apparatus [12]
- measuring strength to bending and uniaxial compression [13]

Analyses were performed on drilling wastes obtained as a result of HDD operations, subjected to dewatering in a filter press and modified at 650ºC.

Numerous analyses of phase composition of drilling waste performed by the authors [8, 9] reveal that clayey minerals, smectites, illite, quartz, calcite, kaolin, and dolomite were their main components. The mineral composition of drilling waste was the mixture of drilled media and drilling mud used for HDD technology, and waste rock from drilling rock intervals.

X-ray analysis of phase composition of drilling mud revealed that in the course of modification of drilling wastes at 650ºC we obtain material containing the following minerals (Fig. 1):

- calcite $CaCO_3$, which is advantageous for calcium carbonate as a factor influencing the strength of the set cement slurry to sulfate corrosion in the sulfate-containing reservoir water conditions
- quartz, undergoing polymorphous transformation into high-temperature quartz
- illite/muscovite – illite undergoing dehydration at 560 to 700ºC. The origin of illite can probably be explained by the fact that the cutting materials contained kaolinite-illite clays. Muscovite (mica), undergoes dehydration only at more than 1000ºC
- kaolinite was also observed to change into highly reactive metakaolinite of high Puzzolan character after being subjected to 450 to 700ºC

After dehydration and being subjected to high temperatures, drilling cuttings were used as mineral additives of industrial Puzzolan character to cement slurries based on blast-furnace cement CEM III/A 32.5 N-LH/HSR/NA produced by Górażdże Cement S.A. This cement was selected for its properties, extensively described in the literature [14-

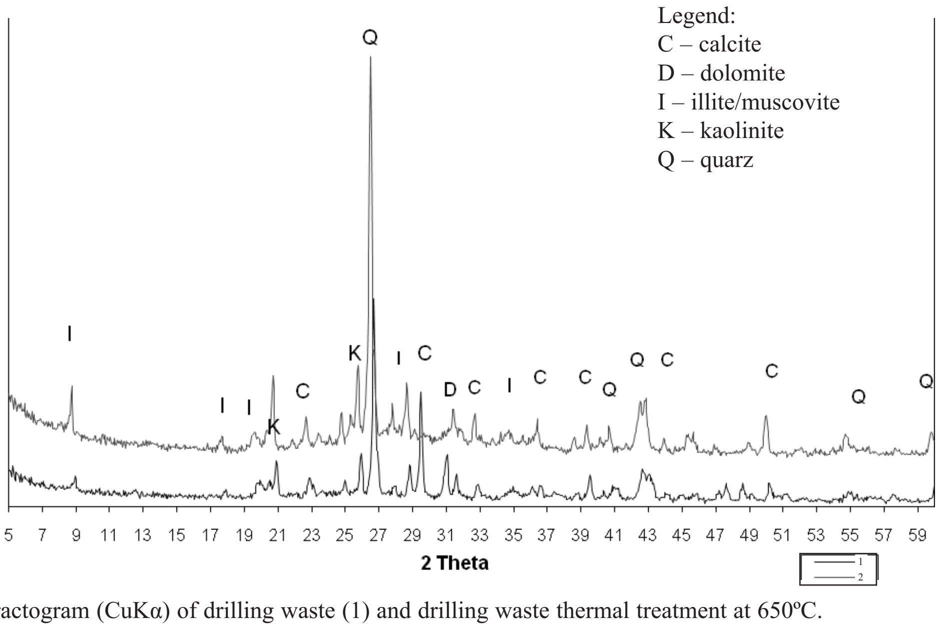

Fig. 1. X-ray diffractogram (CuKα) of drilling waste (1) and drilling waste thermal treatment at 650ºC.

17]. The studied cement slurries were based on network water; the water-to-cement ratio was equal to 0.6, and 20 wt. % of modified waste was added. Slurries based on blast-furnace cement were used as reference samples.

The influence of modified drilling waste on set cement slurries was analyzed in the following way. Two series of 40×40×160 mm test pieces were formed. The first series consisted of slurries containing 20 wt. % of drilling cuttings, and reference samples without waste in their composition were in the other series. The samples matured in forms for two days. Then they were removed and disposed of in water containers, where they spent 28 days. After that time they were subjected to two autoclave cycles. This process took 28 hours at 20 MPa pressure and 180ºC.

Strength tests for bending and compression were performed on these samples.

Results

Table 1 contains results of laboratory analyses of technological parameters of fresh cement slurries containing 20 wt. % cuttings a for water-to-cement ratio of 0.6.

The influence of heating drilling waste on rheological parameters of cement slurries just after they had been made is presented in Table 1. These results were obtained with the use of Rheosolution software for selecting rheological models. Models having the highest correlation coefficient are considered to be best for each of the analyzed cement slurries [18, 19].

The basic requirement set before cement slurries for cementing boreholes is its durability. The influence of thermally modified waste on durability of cement slurries after autoclave treatment was analyzed on the basis of strength tests. Strength to uniaxial compression of autoclaved, set cement slurries with modified waste and the reference slurry was 27.08 MPa and 30.49 MPa, respectively. The strength to bending of modified and reference slurries was 3.98 MPa and 5.38 MPa, respectively.

Table 1. Technological parameters of fresh cement slurries determined in lab conditions at 20ºC (± 2ºC).

Technological parameters of fresh cement slurries of water-to-cement ratio w/c = 0.6	Drilling waste concentration [wt. %]	
	0	20
Density [kg/m^3]	1,730	1,740
Spillability for cone AzNII [mm]	185	160
Proper filtration [cm^3/s]	62.0/10	41.5/25
Beginning of bonding	9 h 45 min	11 h 00 min
End of bonding	16 h 00 min	18 h 15 min
Time of bonding	1 h 15 min	2 h 15 min

The obtained results of bonding times show elongation of both the beginning and end of bonding of slurry with admixed waste. This can be explained when part of the klinker phases is substituted by slowly bonding lime from the cuttings.

The calculated correlation coefficients for specific rheological models presented in Table 2 reveal that the rheological models of slurries do not change. They are described using the Herschel-Bulkley model.

The course of strength to uniaxial compression and bending of set slurries differs, depending on their composition. Cement slurries containing 20 wt. % of thermally modified waste have slightly worse strength parameters as compared to the reference slurry. This is, however, a slight lowering of strength parameters and these slurries can be used in various geoengineering works and for filling out the annular space. Owing to the shallowness of HDD works, the obtained strength of the slurry can be considered as sufficient in a majority of cases.

The studies also reveal that wastes modified as shown in Fig. 2 can be used for sealing the annular space in installations performed using HDD technology.

Discussion of Results

The obtained results of laboratory studies reveal that the analyzed materials can be used for filling out the annular space in directional boreholes. The density of studied slurries was 1,740 kg/m^3, which corresponds to requirements set before cement slurries used for filling out purposes.

The filtration results can be treated as advantageous, as they were lowered from a level of 62.0 cm^3 in 10 s for the reference slurry to a level of 41.5 cm^3 in 25 s for a slurry with an additive. The spillability of slurry containing cuttings also dropped down to a level of 160 mm in cone AzNII. Too low spillability may result in a limited range of flow of cement slurry in the annular space. At the stage of making cement slurries containing thermally modified waste this problem can be solved using superplastifiers, for example.

Conclusions

1. Production of large quantities of waste in HDD and microtunnelling operations is a considerable problem. Storing of this type of waste is the least reasonable utilization method. The problem of drilling cuttings can be solved with environmentally friendly methods.
2. According to the authors, cement slurries containing thermally modified drilling waste used for filling out annular spaces in trenchless boreholes is an ecological alternative to managing this type of waste material.
3. The proposed method of neutralizing drilling waste surely is an ecological solution that has the following advantages:

- organic-mineral neutralization of the cuttings
- the resulting product has Puzzolan properties, applicable as 20 wt. % mineral additive of cement slurries
- lower cement consumption 20 wt. %

Table 2. Rheological parameters determined for various rheological models of cement slurries at 20ºC (±2ºC) [7].

Rheological models	Rheological parameters	Drilling waste concentration [wt. %]	
		0	20
Bingham model	Plastic viscosity [Pa·s]	0.1041	0.1738
	Yield point [Pa]	11.923	28.1923
	Apparent viscosity for 600 rot/min [Pa·s]	0.104	nm*
	Correlation coefficient [-]	0.9688	0.9677
Ostwald de Waele model	Consistency coefficient [Pa·s^n]	2.5706	14.1180
	Exponential [-]	0.5314	0.3068
	Correlation coefficient [-]	0.9958	0.9839
Casson model	Casson viscosity [Pa·s]	0.0787	0.0812
	Yield point [Pa]	4.4862	18.5562
	Correlation coefficient [-]	0.9825	0.9919
Herschel-Bulkley model	Yield point [Pa]	0.4453	13.7151
	Consistency coefficient [Pa·s^n]	2,1439	4.1444
	Exponential [-]	0.5653	0.5018
	Correlation coefficient [-]	0.9978	0.9984

*nm – non-measurable

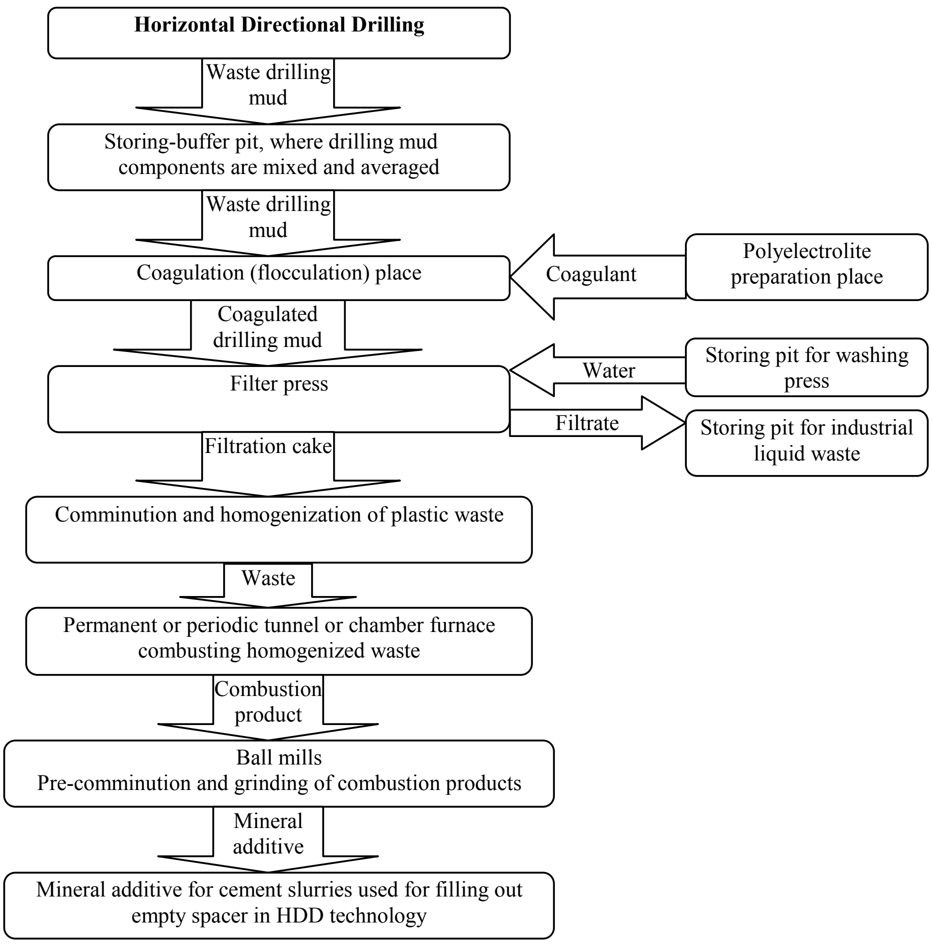

Fig. 2. Technological scheme of production of mineral additive used for slurries employed for filling out annular spaces in horizontal directional boreholes.

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