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Assessment of the cement failure probability using statistical characterization of the strength data

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A R T I C L E I N F O

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A B S T R A C T

Cement sheath failure may occur under the influence of induced stresses during service life of the well. For many years, analytical or numerical models have been developed to study the probability of the cement sheath failure under different circumstances. Cement compressive strength is considered as a valuable input parameter during the assessment of the cement failure probability. Usually the compressive strength data are obtained by conducting several direct laboratory experiments on cement samples. The average value of these experiments are reported and used in different cement failure models. However, this approach may results in underestimating the cement failure probability. As cement have heterogeneous structures, therefore their strength variations have a statistical character. In this work, the compressive strength data are represented by the Weibull distribution function, which then will be used in the cement failure probability calculations. Results show that using the statistically distributed compressive strength data in calculations, leads to more accurate outputs of the failure model.

1. Introduction

Cements are used in the construction of oil and gas wells to fill the annulus space between casing and surrounding rock formation, provide structural integrity to the wellbore, support casing, protect it against corrosion and prevent the unwanted migration of fluids from one layer to another (Tabatabaee Moradi and Nikolaev, 2016). The quality of cementing job defines service life of the well. The cement sheath failure may result in necessity of further workover and well repair operations, which are usually costly and time-consuming. Integrity of the cement sheath may be damaged by induced stresses inside the cement or at its interfaces during completion and production operations (Zhang et al., 2016).

Several researchers investigated cement sheath integrity during the service life of the well by numerical or analytical approaches and predicted the failure of cement sheath. Gholami et al. (2016) presented a thermo-poroelastic model to evaluate the probability of cement sheath failure in deep vertical wells. They indicated the significance of temperature effect on the pressure variations and integrity of the cement sheath. Himmelberg (2014) used a finite element model to predict the cement sheath integrity of a well, proposed for CO_2 sequestration. He investigated the mechanical interactions of the formation, cement and casing, as well as temperature variations effect. In the work of Lavrov et al. (2014), integrity of the near-well zone is studied. Authors numerically modelled the effects of thermal cycling on a «rock--cement-casing » system and concluded that the radial tensile stresses can lead to annular cement debonding. Kim et al. (2016) assessed the shear failure possibility of cement using Mohr–Coulomb failure criterion during the hydraulic fracturing operations. They showed that by increasing hydraulic fracturing pressure and cement permeability, the failure probability of cement would increase.

Compressive strength of the cement systems is considered a valuable input for all cement sheath failure assessment methods. The cement compressive strength data are usually reported as an average value of several direct laboratory experiments. As cements have heterogeneous structure, the results of laboratory measurements of an identical composition may be different. Therefore, this average value may not properly represent the strength characteristics of the cement. Variations of strength properties in ceramic materials like cements inherently have a statistical character (Lu et al., 2002). On this basis, the compressive strength of cement samples can be expressed by means of different statistical distribution functions.

In this work, the cement sheath failure probability of two cement compositions is analyzed using the known Mohr-Coulomb failure criterion, where the compressive strength and mechanical properties of systems are entered into the failure model as statistically distributed variables.

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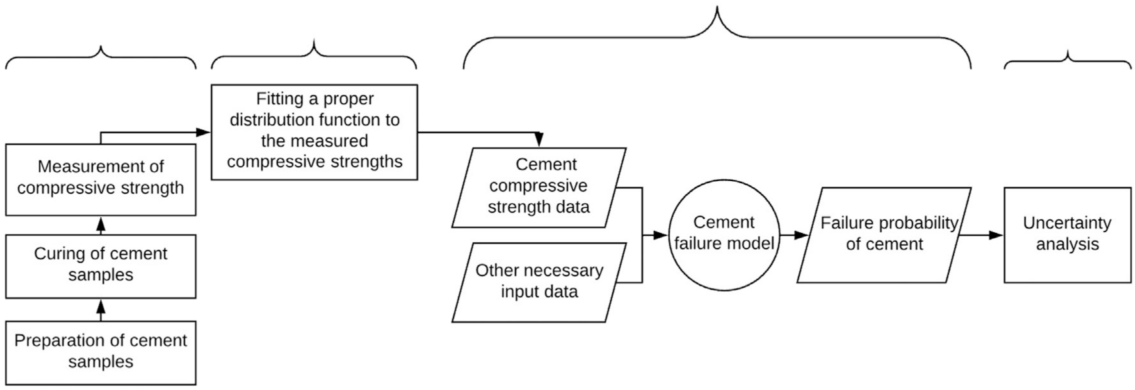

Fig. 1. Workflow chart.

2. Material and methods

The workflow of this study (Fig. 1) consists of four main parts. During part I, the cement samples are prepared, cured and then tested for compressive strength. In part II, a statistical distribution function is fitted to data, which were resulted from laboratory tests and the parameters of the distribution are found. Failure probabilities of the developed cement compositions are estimated in part III, during which the compressive strength data (as a distribution function or as an average value) are entered into the failure model along the other necessary input data. Finally, in part IV, uncertainties, associated with the calculated failure probabilities are estimated to check the validity of results.

2.1. Part I: Experimental investigations

The cementitious material considered in this work is an ordinary Portland cement provided by the local producers with the following composition (wt.%): 61.34 C_3S, 14.61 C_2S, 5.49 C_3A, 16.62 C_4AF. Silica flour, with a mean particle size of 20 μm, is used to provide high mechanical properties by optimizing the material compactness and reducing the strength retrogression of the cement at high temperatures. Other components of the cement compositions, with a total mass of less than 4% by weight of the dry blend, include an antifoam agent, lignosulfonate retarder and a clay mineral (attapulgite) as anti-settling agent.

In this work, two cement compositions with and without silica flour are considered (Table 1). Both compositions are prepared based on the standard procedures, which involve dry premixing of Portland cement and silica flour. The retarder, attapulgite and antifoam agent are added directly to the water and mixed manually. Then, dry composition and water were mixed for 3 min. The water-to-cement mass ratio for all systems is w/c = 0.5.

Thirty-two samples of each cement composition are prepared and casted into cylindrical steel moulds (Fig. 2), which are then, for curing purposes, placed in a high-temperature, high-pressure cell (T = 120 °C, P = 1 MPa), where pressure was imposed with CO_2 gas. After 24 h curing, samples are demoulded and left inside water for three days. The samples are tested by a PILOT compression-flexural cement tester (Fig. 3) and the compressive strength data for both cement compositions are determined (Appendix A).

Table 1
Different cement compositions considered in this work.

Composition	Blend materials, % mass concentration		Other additives, % by the weight of the blend		
	Portland cement	Silica flour	Lignosulfonate	Attapulgite	Antifoam agent
a	100	–	1	2	0.5
b	80	20	1	2	0.5

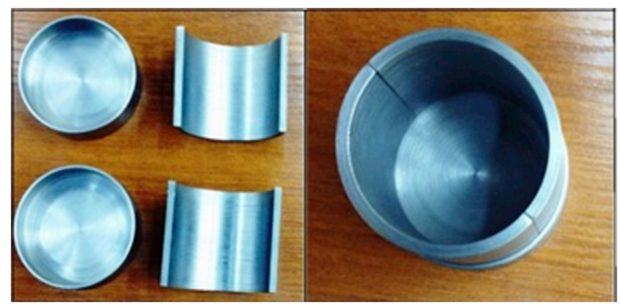

Fig. 2. Cylindrical steel moulds (diameter 40 mm, height 40 mm).

Fig. 3. PILOT compression-flexural cement tester.