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Compressibility of materials and backfilling mixtures with addition of solid wastes from flue-gas treatment and fly ashes

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Abstract. The article presents laboratory tests of pressure - compressibility characteristics of materials and backfilling. The tests were carried out for three different types of backfilling: rock fill (dry), hydraulic and paste in oedometers for three different volume configurations with the addition of waste from flue-gas treatment or in the form of fly ash. For the rock fill, compressibility was determined for the backfilling made only from dolomite, while in subsequent tests 50% and 25% by volume of the waste from the flue-gas treatment were added to the backfilling material, respectively. In the case of hydraulic backfilling, the mixture was sand mixed with water and fly ash in a fixed ratio: a mixture of sand and water in a 1:1 ratio, a mixture of sand with water and fly ash in a volume ratio of 50% sand with water and 50% fly ash and 75% sand with water and 25% fly ash. The last type of research was paste backfilling, for which compressibility was determined for a mixture of waste (fly ash), binder and water in a volume ratio of: 50% fly ash, 40%, 45% and 48% water and 10%, 5% and 2% binder.

1 Introduction

Backfilling in mining excavations is one of the beast methods of liquidation of the underground post-mining areas. It is mainly used for facilitating and sometimes allowing underground exploitation of thick and very thick deposits. Furthemore it is successfully used in underground coal, ore and salt mines to solve many environmental problems [1, 2], including coal extraction under buildings and surface subsidence [3, 4]. Very often backfilling is considered as green mining technology in which the solid waste materials is placed into the gob to support the overlying strata and to control roof's subsidence and movement [5]. In addition, hydraulic backfilling, it is one of the most effective methods to protect against underground fires, rock burst [6] and water intrusion. Its use also reduces the losses of the exploited deposit. The use of backfilling in general causes, in each case, a reduction in subsidence of the surface, and thus limitation of mining damage, and makes it possible to deposit waste in underground mining excavations. The size of subsidence can be regulated, among others within certain limits of the exploitation system of the discussed area, as well as the quality of the backfill, mainly the size of its compressibility, often referred to as the compressibility index. The admissible size of this indicator will depend on the character of the surface development. Determination of the permissible size of the compressibility index for the considered case and the appropriate selection of mixtures and types of backfilling material in laboratory conditions - allows the use of various materials as backfilling material, and also allows prediction of the effects of surface exploitation. In turn, such results form the basis for making a decision about exploitation and how to carry it out in the so-called hampered conditions. This makes it possible to use exploitation in a protecting pillars sometimes under very sensitive objects, such as: steel mills or power plants, including shaft pillars.

2 Types of backfills

Filling is a material or materials used to fill voids arose during mining operations. Several methods of backfilling the developed voids, such as the hydraulic backfill, cemented paste backfill, rock backfill and silica alumina-based backill methods have been proposed [7]. The filling of mining excavations can be divided into the following types of backfills:

- rock fill (in Poland, used only in the mining of copper ore deposits in the Legnica-Głogów Copper District),
- hydraulic (in 2016 in Polish mines the use of filling sand was as follows: KGHM mines used about 1.0 million m3, the "Olkusz-Pomorzany" mine belonging to ZGH "Bolesław" 1.035 mln m3 and Wieliczka salt mine about 0.188 mln m3. In coal mines in 2016, one backfilling wall was used in the "Wujek" mine, where about 0.263 mln m3 of sand was used [8],

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- hardened (used in Poland in the sixties of the last century to mine Zn-Pb ores deposited in protective pillars, the binding material was cement, and the material filling sand or dolomite aggregate),
- special (self-stabilizing) - this technology is based on binding properties exhibited by most fly ash. The filling mixture after solidification in the sealed excavation creates a compact mass of a certain strength, capable of supporting the floor rocks and transferring the loads of the superjacent - above layers. In the case of weak binding properties of fly ash or the need to obtain a backfill with certain strength parameters, it is necessary to add other binding agents, such as: cement, lime, gypsum, anhydrite,
- special (paste) - is a mixture of fine solid particles together with the binder and water (currently in Poland, conceptual and laboratory studies are underway to determine the applicability - locating wastes in underground salt excavations) [9, 10]. In many Canadian underground mines, the use of cemented rockfill as backfill material is a common practice [11, 12].

Each material provided as a backfilling material or addition in a given quantity to the backfilling material requires its properties to be determined and the determination of the backfill created from it. This is determined by means of appropriate laboratory tests. For example, for the hydraulic backfill, the physical properties of the materials for the hydraulic backfill were characterized in Polish Norm PN-G-11010: 1993 [13] and for materials, mixtures of materials, solidified fill and sealing of goaf were presented in Polish Norm PN-G-11011:1998 [14].

2.1 Formatting the title, authors and affiliations

The backfilling with the use of waste rocks (dry filling) consists in filling the post-mining space with rock material obtained from mine excavations or brought from the surface without using water. It is particularly advantageous for environmental reasons because waste rocks are not stored on the surface. The waste rocks fill the selected space and constitute a work platform for the movement of machines in a higher layer (Fig. 1A and 1B). The transport of waste rocks are carried out using mining dumpers. A rock fill (dry backing) is also used in room and pillar mining systems, where waste rocks are located between rooms pillars in the phase of liquidation of excavation.

2.2 Hydraulic backfill

In the case of using hydraulic backfill, backfilling is based on the gravitational hydrotransport of the mixture formed mainly from water and backfilling material with special pipelines from the surface up to the forehead (Figures 2A, 2B). According to the invalid standard (PN-93/G-11010), the material for hydraulic backfilling could be: sand, gravel, waste (slag, waste rocks, industrial waste, etc.). The backfilling material is embedded in the sealed space of the exploited excavation, filling it, what they called the right backfill, and the water that fulfills the task of the factor allowing the flow of backfilling material, draining away free flow (gravitationally) to the roadway and further to underground water tanks, eg settlers. The basic backfilling material for hydraulic backfilling is backfilling sand. At the same time, although in a smaller amount, as fill material or as an admixture for filling material, various kinds of industrial wastes, such as mining wastes separated in the processing plant, waste rocks from the preparatory operations, etc. and various types of slag, ashes, old heaps.

For materials to be used for hydraulic backfill or backfilling mixtures, physicochemical properties should be determined. For the filling sand, the scope and methodology of the tests was defined in the PN-93 / G-11010 standard in force in 1993-2014 (PN-93 / G-11010). Despite its withdrawal, an assessment is still made on its basis to ensure the proper properties of the mixture of sand and water, which will eliminate the risk of cork formation in backfilling installations. In addition, suitable parameters of backfilling sand allow proper cooperation of the backfill with the rock mass.

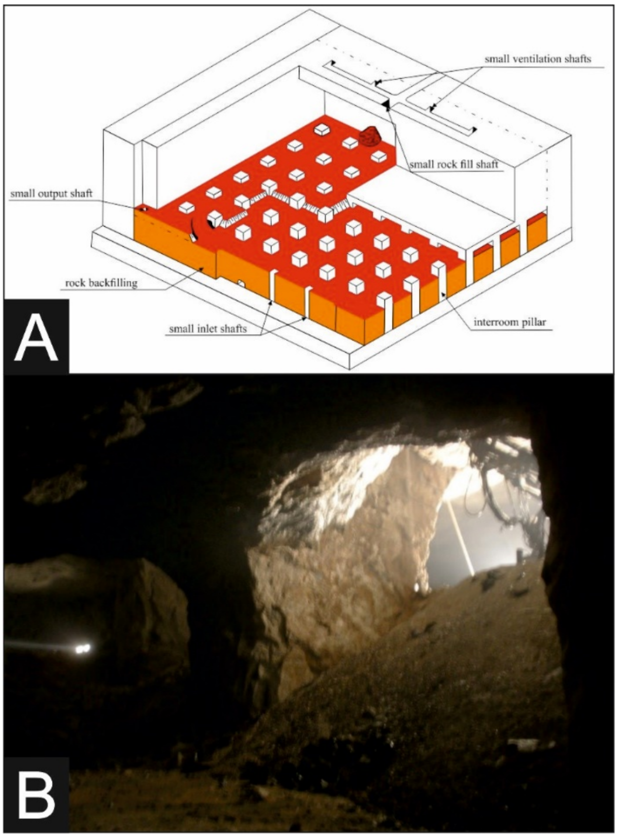

Fig. 1. Backfilling of excavation by means of rock fill (dry filling) from the upper layer in the room and pillar mining system with division of horizontal layers in the Magnesite mine (SMZ, a.s. Jelšava); A) general view; B) a view of self-propeled drilling machine located at the backfilled layer.

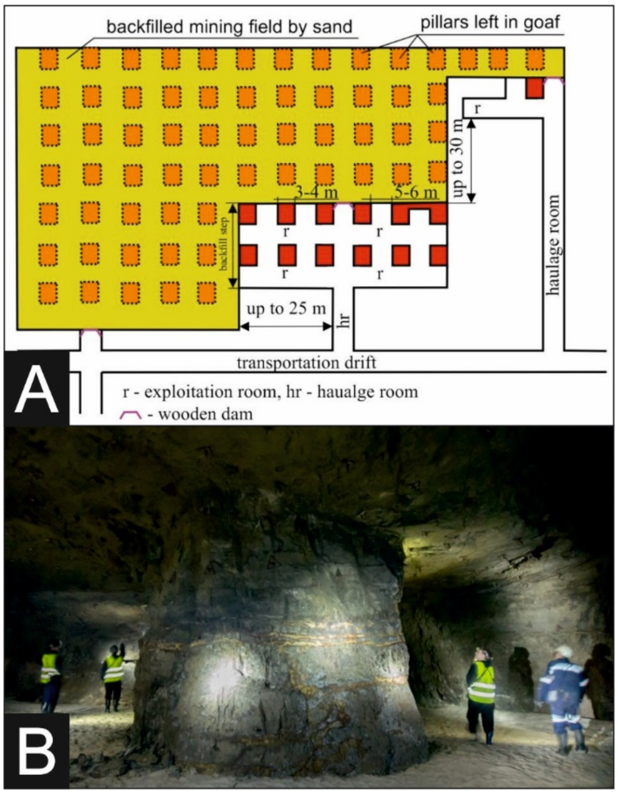

Fig. 2. Hydraulic backfilling in the Zinc and Lead „Olkusz-Pomorzany" Mine; A) top view of scheme of room and pillar mining system of exploitation; B) view of the system with visible sand from the first layer on the floor of the excavation.

2.3 Paste backfill

The paste filling is a high density filling (several dozen percent solid particles depending on the specific gravity). When pumping such a dense material, high fineness of components is required. The paste filling is pumped using piston pumps. For the production of paste, it can use fine waste, so that the final product is more dense due to the lower air content. Many mines introduce the use of paste filling due to lower cement consumption in order to obtain comparable strength as in the case of hydraulic backfill. The paste filling is a mixture of fine solid particles together with the binder and water. The advantages of the paste filling are: higher strength can be achieved by the equivalent content of cement, minimizing the need to remove water and mules from the backfill by reducing the need to construct partitions and extensive drainage works. In some cases unclassified waste can be used to produce paste more than only coarse fractions, shorter cycle time can be achieved by faster achieving adequate strength by pasting. Pasting systems achieve lower porosity by increasing the load capacity of the material, which can be deposited underground, paste filling as a non-segregating mass can achieve higher strength properties. The disadvantages of the past filling are: pasting filling systems have higher main costs compared to a typical hydraulic filling; the workability of the paste is very sensitive to small changes in water content and aggregate grain size; the distribution network in the mine requires a well-designed pipeline control system. Currently in the "Kłodawa" Salt Mine S.A. it is possible to adapt from 3 to 3.5 mln m3 of room workings (post-mining voids) where it can start the process of waste storage and simultaneously carry out the basic mining activity. The room workings in salt, due to their huge geometry, are perfect for storing enormous amounts of waste (Fig. 3). Ultimately, this area, along with the progress of exploitation, will increase until it reaches the possibility of storage in a large part of mine workings [15].

Fig. 3. Room excavation in Kłodawa Salt Mine.

3 Laboratory tests of materials and backfilling mixtures

3.1 Description of laboratory tests

Laboratory tests of compressibility of materials and backfilling mixtures were performed at the Department of Underground Mining. The aim of the research was to determine the pressure-compressibility characteristics. The tests were carried out for three different types of backfilling, i.e. rock fill (dry), hydraulic and paste. For each type of filling, tests were carried out in oedometers (Fig. 4) for three different volume configurations with the addition of waste from flue-gas treatment filters or in the form of fly ash (Figs. 5A – 5L). The choice of

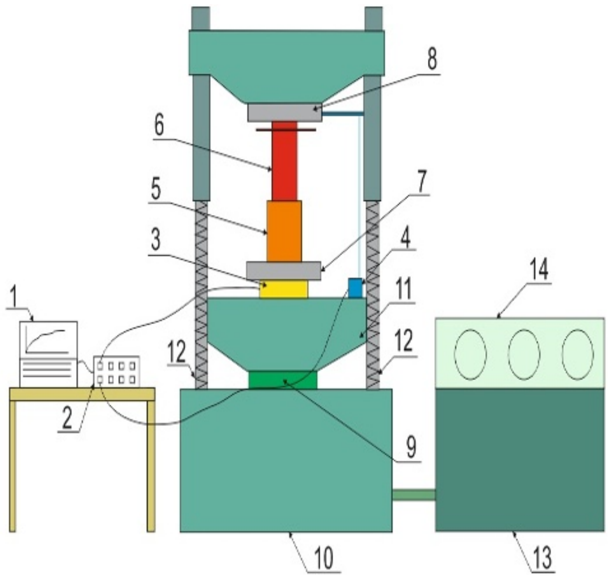

Fig. 4. Diagram of laboratory station to determine compressibility; 1 – computer, 2 - measuring amplifier, 3 - load cell, 4 - displacement sensor (wire encoder), 5 – cylinder, 6 – piston, 7 - bottom base, 8 - upper plate, 9 - hydraulic cylinder, 10 - machine base, 11 - driven cross head, 12 – screw, 13 - hydraulic pump, 14 – control panel.

proportion configuration resulted from the possibility of the largest possible management of waste and from the researches that are done in the world [16,v17]. The backfilling material for the rock fill (dry backfill) was a fragmented dolomite from the underground Zinc and Lead "Olkusz – Pomorzany" Mine. The crushed dolomite pieces were up 30mm in size. For the rock fill (dry backfill), compressibility was determined for the filling made only from dolomite, while in subsequent tests 50% and 25% by volume of the waste from the flue-gas treatment filters were added to the backfilling material, respectively. In the case of hydraulic backfill, the mixture was sand with a grain size up to 2mm mixed with water and fly ash in a fixed ratio: a mixture of sand and water in a 1:1 ratio, a mixture of sand with water and water ash in a volume ratio of 50% sand with water and 50 % fly ash and 75% sand with water and 25% fly ash. The last type of research was paste filling, for which compressibility was determined for a mixture of waste (fly ash) binder and water in a volume ratio of: 50% fly ash, 40%, 45% and 48% water and 10%, 5% and 2% binder. The characteristics of fly ash and solid waste from flue-gas treatment filters are presented in the article [10].

3.2 Backfill characteristics in a layout pressure – compressibility

On the laboratory station, the force measurement was carried out by means of a strain gauge force sensor with a nominal value of 500 kN, while the measurement of deformation by means of an incremental encoder with a cable length of 1000 mm. The sensors were connected to the universal measuring amplifier QuantumMX 840A. The results were recorded on an ongoing basis using the CatmanEasy program. The following formula was used to calculate the compressibility (C_b):

$$C_b = \frac{H_0 - H_p}{H_0} \cdot 100 \tag{1}$$

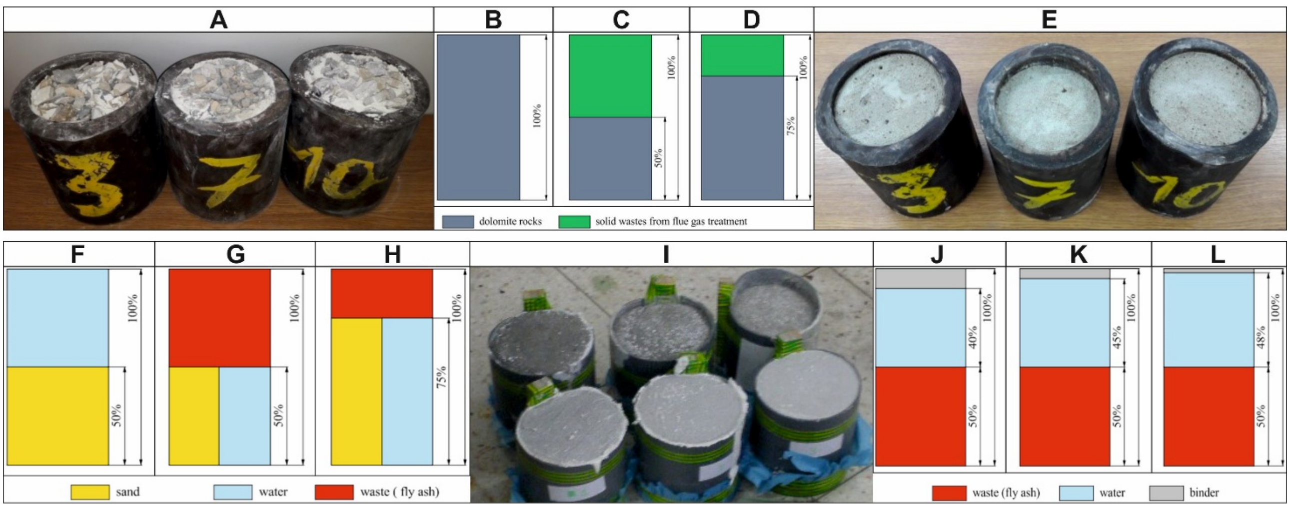

Fig. 5. Configurations of backfilling: A) rock (dolomite) backfill with waste – general view; B) rock (dolomite) backfill – only dolomite waste rocks; C) rock (dolomite) backfill – mixture of waste rocks + flue-gas treatment in a volume 50%; D) rock (dolomite) backfill – mixture of waste rocks + flue-gas treatment in a volume 25%; E) hydraulic backfill – general view mixture with waste (fly ash); F) hydraulic backfill – mixture of sand + water in a volume ratio 1:1; G) hydraulic backfill – mixture in a volume ratio 50% sand + water and 50% waste (fly ash); H) hydraulic backfill – mixture in a volume ratio 75% sand + water and 25% waste (fly ash); I) paste backfill – general view; J) paste backfill – mixture of waste (fly ash) 50%, water 40% and binder 10% in a volume ratio; K) paste backfill – mixture of waste (fly ash) 50%, water 45% and binder 5% in a volume ratio; L) paste backfill – mixture of waste (fly ash) 50%, water 48% and binder 2% in a volume ratio.

where:
H_0 – height of material of mixture bacfill in a oedometer before compression,
H_p – height of material of mixture bacfill in a oedometer after compression.

The results of the tests are presented in Figs. 6 to 8, while Fig. 9 presents an overview of the compressibility results of individual types of backfill.

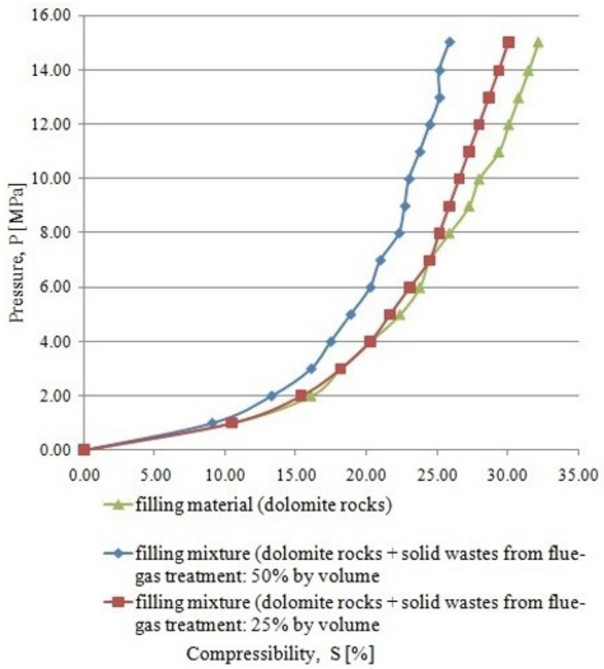

Fig. 6. Pressure – compressibility characteristics for rock fill - dolomite (dry backfill) with solid waste from flue – gas treatment.

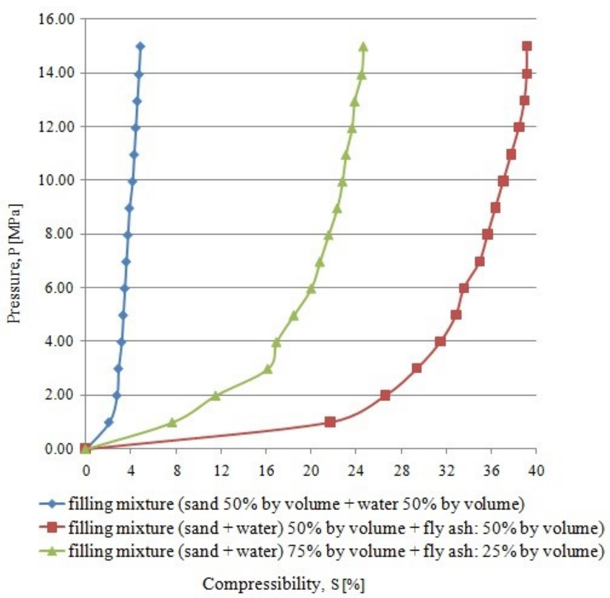

Fig. 7. Pressure – compressibility characteristics for hydraulic backfilling with solid waste in form of fly ash.

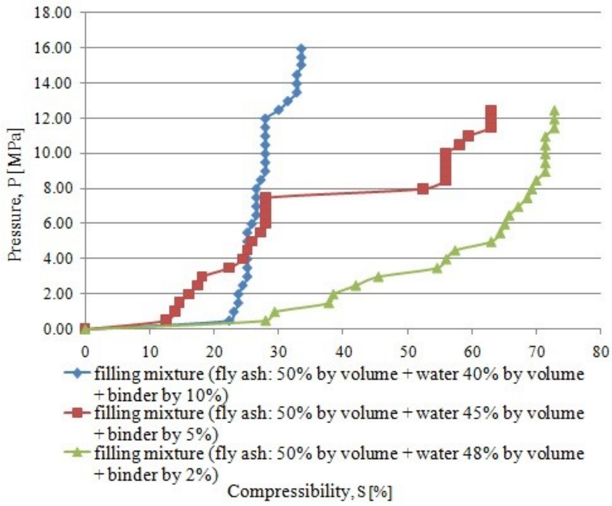

Fig. 8. Pressure – compressibility characteristics for paste backfilling with solid waste in form of fly ash.

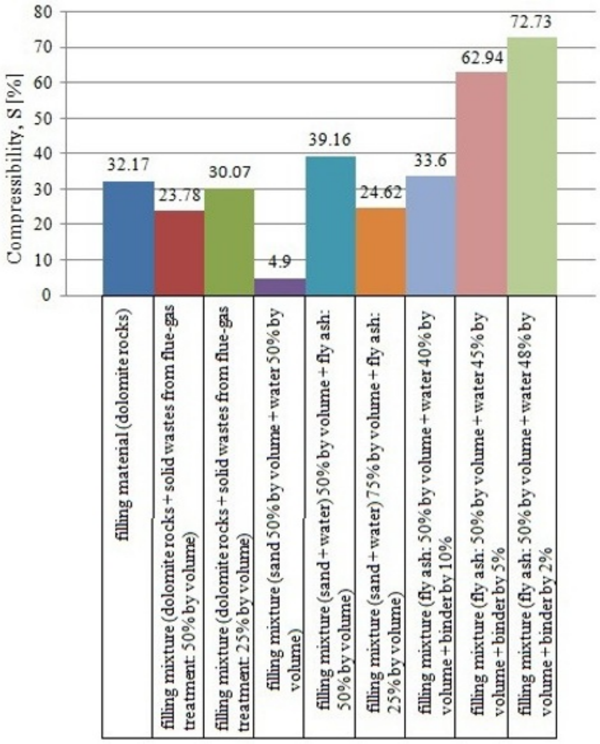

Fig. 9. Comparison of compressibility of different types of backfillings.

On the basis of Fig. 9, it can be concluded that for the rock fill (dry filling) addition of waste in form of flue-gas treatment in the amount of 50% by volume, it reduces the compressibility by 26% compared to the dry proposition formed only from the waste rocks - dolomites itself. The addition of 25% by volume of waste reduces the compressibility by only 6.5%. Much bigger differences were obtained in the case of hydraulic backfill. Compressibility of a mixture of sand and water (4.9%) qualifies this mixture for the first class of compressibility according to Polish Norm PN-G-11010: 1993 [13]. The addition of fly ash in a volume of 50% causes an eight-times increase in compressibility, while for the additive in an amount of 25% by volume, this increase is up to five-times in relation to the backfill formed only from sand and water. In the case of compressibility for the paste filling, compressibility of 15 MPa was obtained only for the mixture in which the binder content was 10%. In other cases, i.e. for 2% and 5% of the binder, the maximum pressure was 12.45 MPa. Nevertheless, comparing the compressibility of the paste filling mixture, it can be concluded that at 5% of the binder, the compressibility increases by 187% and at a content of 2% binder, the compressibility increases by 216% compared to the content of 10% binder.

4 Conclusions

For the rock fill (dry filling) created from waste rocks, it is possible to locate it in underground mining excavations by transporting with trucks or pipelines of compressed air (expensive solution). Laboratory tests shown that the addition of fly ash (25% by volume) does not cause significant changes in compressibility. Only the 50% additive results in a 26% change in compressibility. For the underground exploitation of zinc and lead ore deposits in the case of exploitation of a large deposit, it is worth considering liquidation of the post-mining area even if only in one (last) layer using waste rocks with the addition of waste. In the case of hydraulic backfilling - filling sand, besides being used in the classic hydraulic backfill, is used in t mixtures used for natural hazards prevention. It is worth noting that the addition of waste (in the form of flue gas treatment) in both 25% and 50% by volume significantly reduces its features, which is of decisive importance in the case of surface protection. Nevertheless, the mixture of sand and water is still the basic method of liquidation of the post-mining area in the underground lead and zinc ore mine at a depth of 100 m below the surface area. The compressibility tests for paste backfilling were aimed at presenting the possibility of locating waste in the form of fly ash in underground salt mining. Although the compressibility results are not satisfactory, because only for the mixture with the addition of 10% of the binder, compressibility of 15 MPa was obtained, it should be stated that the geometry of salt rooms 15m wide, 15m high and from 100 m to 400 m long, creates excellent opportunities for depositing waste in a huge amount. In addition, taking into account the rheological phenomena that occur in underground salt mining, the basic task of the past filling would only be to fill the post-mining voids, while the aspect of reducing the impact on the reduction of the area would only be an added value to a negligible extent.

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References

1. L. Yang, E. Yilmaz, J. Li, H. Liu, H. Jiang, Construction and Building Materials, **187** (2018)
2. J.C. Wilson, S. Benbow, R. Metcalfe, Cement and Concrete Research, **111** (2018)
3. X. Feng, N. Zhang, L. Gong, F. Xue, X. Zheng, Energies, **8**, 5 (2015)
4. W. Sun, H. Wang, K. Hou, Journal of Cleaner Production, **171** (2018)
5. J. Feng, H Peng, G. Shuai, X. Meng, L. Lixin, International Journal of Mining Science and Technology, **27** (2017)
6. Y. Xue, Z. Cao, F. Du, L. Zhu, Sustainability, **10**, 8 (2018)
7. Y. Huang, J. Li, T. Song, G Kong, M. Li, Energies, **10**, 1 (2017)
8. Ł. Herezy, K. Skrzypkowski, P. Kamiński P, Ores and Non-ferrous Metals, **63**, 2 (2018)
9. W. Korzeniowski, K. Poborska-Młynarska, K. Skrzypkowski, Archives of Mining Science, **63**, 3 (2018)
10. K. Skrzypkowski, W. Korzeniowski, K. Poborska-Młynarska, Archives of Mining Science, **63**, 4 (2018)
11. M. Sepehri, D.B. Apel, R. A. Hall, International Journal of Rock Mechanics and Mining Sciences, **100,** (2017)
12. B.A. Lingga, D.B. Apel, Journal of Rock Mechanics and Geotechnical Engineering, **10**, (2018)
13. PN-G-11010, Polish Norm – Materials for hydraulic backfilling. Specifications and tests (1993)
14. PN-G-11011, Polish Norm – Materials for solidified backfilling and goaf sealing. Specifications and tests (1998)
15. W. Korzeniowski, K. Poborska-Młynarska, G. Bartłomiejczak, XII international conference, Thermal treatment of waste – from plans to implementation: it's time to start the operation of the incineration plants (2015)
16. K.J. Lee, S. K. Kim, K. H. Lee, Materials, **7** (2014)
17. K. Zhou, R Gao, F. Gao, Minerals, **7**, 1 (2017)