Mining Science, vol. 28, 2021, 7–18

www.miningscience.pwr.edu.pl

Mining Science

(Previously Prace Naukowe Instytutu Gornictwa Politechniki Wroclawskiej, ISSN 0370-0798)

ISSN 2300-9586 (print)
ISSN 2353-5423 (online)

Received September 26, 2020; Reviewed; Accepted February 21, 2021

EFFECTIVE METHODS OF CHALCEDONITE PROCESSING

Zdzisław NAZIEMIEC[1]
Daniel SARAMAK[2]*

[1] Instytut Ceramiki i Materiałów Budowlanych, Oddział SIMB Kraków, Poland
[2] AGH University of Science and Technology, Kraków, Poland

Abstract: Chalcedonite is an unique mineral with high variability in its density, which may cause problems in its industrial utilization. This study was aimed to find more effective methods for chalcedonite processing based on density separation. The method presented in the paper has been patented, and the results from this study showed that separation product were of a higher quality. Products of density separation have also lower variations in their density values what may results in their more effective industrial utilization.

Keywords: *chalcedonite, density separation, raw material processing*

1. INTRODUCTION

Chalcedonite (silicon dioxide, SiO_2) is a specific raw material, due to limited area of occurrence of this siliceous rock. This mineral can be utilized in production of blends in road construction, as a filter material for water purification and waste water treatment, and in cement industry, (Tchorzewska et al. 2001; Kosk 2010; Michel 2011; 2012). The uniqueness of this material and a wide range of its potential industrial applications requires that the technological process of chalcedonite enrichment should be carried out in a manner which ensures the optimal utilization of this valuable material.

The variety of chalcedonite in terms of its petrographic composition creates significant variability in some physical and mechanical properites (Ratajczak, Wyszomirski

* Corresponding author: dsaramak@agh.edu.pl (D. Saramak)

doi: 10.37190/MSC212801

1991; Tchorzewska 1995), such as its density and water absorption. For example, particles of natural aggregates usually have a density within the range 2.5–2.7 Mg/m^3 having different porosity and water absorption values, and they are usually mixed in the rock deposit, which causes that selective mining of this mineral is not possible. However, an application of separation for aggregate particles with different density and water absorption may be beneficial due to possibility of optimal utilization of the obtained products. These possibilities of chalcedonite processing, based on its density properties (patented), are presented in the paper. Results of investigation into this issue are presented in the article together with selected issues concerning its properties and processing technology.

2. CHALCEDONITE PROPERTIES AND INDUSTRIAL APPLICATIONS

Chalcedonite mainly consists of cryptocrystalline and microcrystalline chalcedony, and contains small amounts of autogenous and detrital quartz. A characteristic feature of all types of chalcedonite are the pores (voids) which are present in various amounts (Kosk 2008). Depending on the area of its origin and the method of mechanical processing, chalcedonite products may be characterized by some variability in chemical composition. Chalcedonite run-of-mine consists of more than 95% of SiO_2, together with small amounts of Al_2O_3 and Fe_2O_3 (Final Report 1997).

Chalcedonite is the subject of much research and practical utilisation, due to its uniqueness. Description of its multiple applications can be found in numerous publications (Ratajczak, Wyszomirski 1991; Tchorzewska et al. 1997; Michel 2011). The basic direction of its utilization is the production of aggregates and mixtures of aggregates used in road construction. Some properties of chalcedonite aggregates are presented in Table 1.

Table 1. Properties of chalcedonite aggregates produced in "Inowłódz" Mine

Feature of aggregate	Particle size of tested aggregate		
	Fine (2-8 mm)	Medium (8-16 mm)	Coarse (16-32 mm)
Dust content, %	3.3	5.8	1.8
Flatness index , %	12	9	14
Frost resistance, %	1.0	1.9	0.5
Density ρ_a, Mg/m^3	2.50	2.44	2.39
Density ρ_{rd} , Mg/m^3	1.78	1.80	1.90
Density ρ_{ssd} , Mg/m^3	2.06	2.07	2.10
Adsorbability, %	16.4	14.5	10.8

Chalcedonite as a component of concrete mixes is of producing the concrete of a class C 25/30 type. In investigations of the freezing resistance, subjected to 150 cycles of freezing/defrosting, decrease in compressive strength of chalcedonite concrete aggregate was not observed. Despite relatively good quality parameters of the concrete, aggregate chalcedonite is not used for concrete production, due to its high absorbability. Chalcedonite aggregate is also not commonly applied in concrete production, despite the mineral is characterized with relatively good qualitative parameters of the concrete. This is due to its high water absorption, which increases the water-to-cement (w/c) ratio in the concrete mix. The (w/c) ratio in the concrete should not exceed 0.6. Chalcedonite's water absorption of 14%, produces a w/c ratio of approximately 0.76. However, utilisation of aggregate with a water absorption of approximately 10% produces suitable consistency of concrete, with a w/c ratio lower than 0.6. Nevertheless, the road construction sector is not optimal method of industrial utilization of chalcedonite. A more efficient direction of its utilization is its application as a gravel bed filter in the processes of water and wastewater treatment (Tchorzewska 1995; Tchorzewska 2001; Kosk 2008; Michel 2011), as an additive to cement clinker production (Garbacik 2005), and in production of light artificial aggregates (Goralczyk et al. 2009).

Significant amounts of fine particles and mineral composition, where the amorphous silica (microcrystalline) dominates, causing the firing process to require lower energy consumption. It was utilized in working out the recipe for the light artificial aggregate (patented), with properties similar to the natural perlite (Kosk 2000). In the pilot plant of OSIMB (Glass and Building Materials Department in Cracow) research institute, it was investigated to obtain the perlite-like aggregates in plant scale. The sorption tests on the material were performed vs. the anthracite coal, which is commonly used in filtration processes. It turned out that total pore volume for this aggregate was much higher (V_c = 0.064 cm^3/g), compared to anthracite coal (V_c = 0.011 cm^3/g).

3. TECHNOLOGY OF CHALCEDONITE PROCESSING

The technological process of chalcedonite treatment includes in general operations of crushing, washing, and classification. An example technological circuit of chalcedonite processing is seen in Fig. 1.

The washing process is of a key-importance in chalcedonite processing, due to the high content of mineral dust in the raw material. The high ash content is very unfavorable in the case of application of chalcedonite in concrete production. However, the washing process of chalcedonite by means of conventional washing devices, is of a rather low effectiveness, because the ash contents of a good quality washed aggregates should be generally lower than 0.5%. Good results of washing process were achieved, when a high-pressure washing device and turbo washers were applied into the process (Naziemiec 2011; Łagowski, Saramak 2017). Turbo washer treatment resulted in dust content not exceeding 1%.

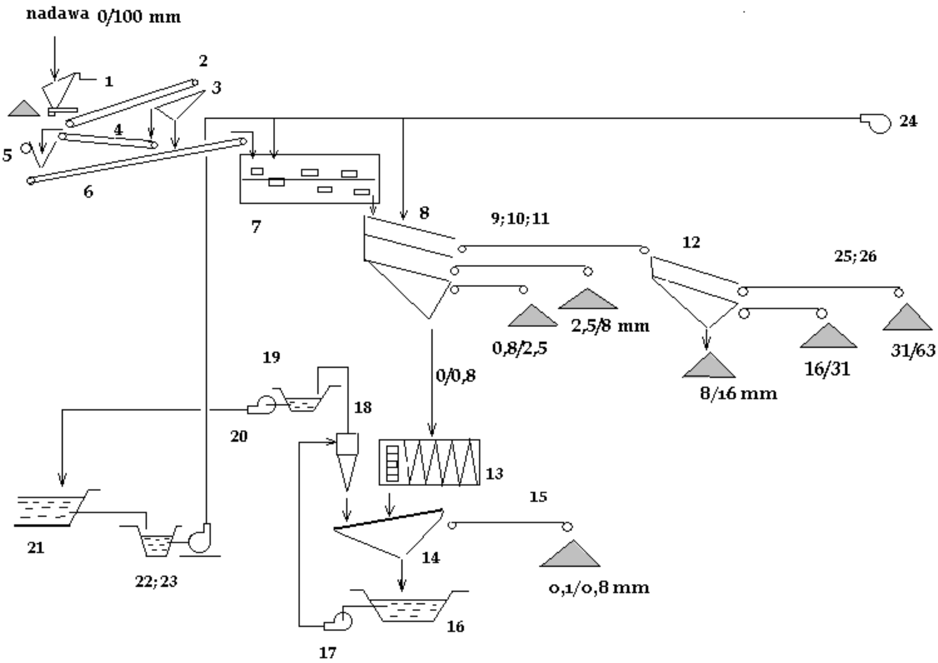

Fig. 1. Technological circuit of chalcedonite processing in "Inowłódz" Mine

In the process of granulometric classification, the particle size fraction 0-0.3 mm constitutes the tailings and usually they are sent to the settling tank. However, it is possible to divide that material into narrower particle size fractions with different chemical composition, which has determined its further industrial application. The separation products, indeed, were characterized by significant differences in mineralogical com-

Table 2. Mineralogical composition of individual particle size fractions for chalcedonite from settling tank

Particle size mm	Mineral type	Content %
0-0.3	Quartz Kaolinite	96.5 3.5
0-0.063	Quartz Kaolinite Illite	75.7 17.5 6.8

position, depending on the particle size. In the case of fine product clay minerals content is higher, while the coarser product contains a large amount of silica, as presented in Table 2.

Figure 2, in turn, shows the separation curves for 0-0.3 mm feed material obtained in a classifier. A relatively high efficiency of separation can be seen for that device. The cut-point for that separator was 0.044 mm. Results from cyclone separation are also presented as an alternative. Cyclone treatment might be more convenient in a plant scale due to greater regulation and process control possibilities through suitable selection of inlet, outflow and overflow nozzles.

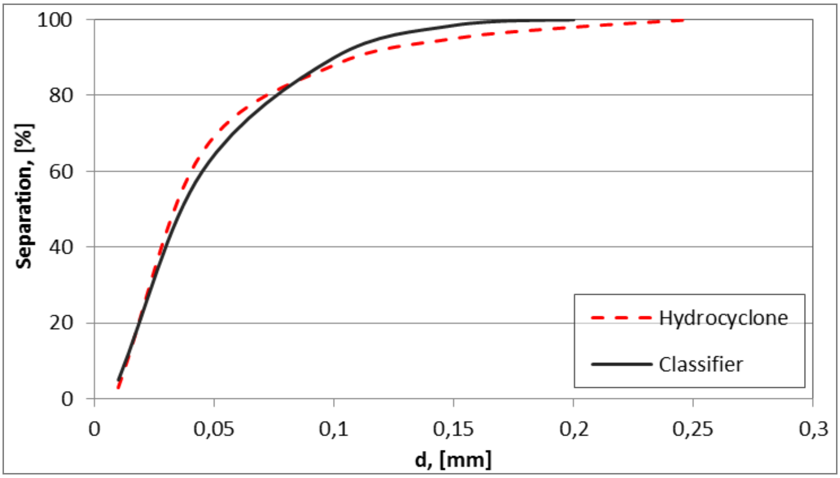

Fig. 2. Separation curves for hydrocyclone and classifier

Products of the chalcedonite size separation, apart from traditional applications in the manufacture of lightweight aggregate and cement clinker, can be used in ceramic technology for dyeing of chalcedonite products, due to the high efficiency of incorporation of hematite into the porous structure of chalcedonite (Naziemiec et al. 2015).

4. EFFECTIVE METHOD OF CHALCEDONITE SEPARATION BASED ON ITS DENSITY

Up-to-date, research on chalcedonite aggregates separation was based on average products obtained from the raw material from different areas of exploitation, after their treatment in crushing, washing, and screening operations.. In order to provide optimal utilization of this unique raw material, separation tests in pulsating jig were carried out.

So far, the operation of density classification has not been tested, therefore the research concerning the results of density separation of chalcedonite, is presented below (the method is under patent granting procedure). The aim of this study was to obtain products with different densities and water absorption values. As a result of the jig separation process, grits for concrete with much less water absorption can be obtained, as well as filtration grits with increased porosity and permeability. These features are important in both the case of application as concrete grit, and in using them as fillers for water purification filters. Grits with lower water absorption guarantee obtaining the concrete with favorable qualitative parameters. However, in the production of filter grits, the high porosity and surface area of the grits are significant features. Regular filter grits with a particle size from 0.8 to 2.5 mm, have the specific surface area of 5 m^2/g, approximately. After chalcedonite separation process using the jig, the grits with a specific surface area of 7.0 m^2/g and a porosity of up to 30%, can be obtained. The porosity of the bottom jig product was around 20%. The grit of greater porosity can be also utilized for horticultural purposes, as they can retain larger amount of water.

Considering the above, **in the first stage of investigative programme**, the separation of chalcedonite by a laboratory jig was carried out. The feed material in two particle size fractions was under investigation: 4-8 mm, and 8-16 mm. The separation product from the jig was divided into four horizontal layers, where the very bottom layer was denoted as layer 1, and the very upper layer – as layer 4. There were also two layers in between the layers 1 and 4. There were determined three types of densities of each separation products:

- ρ_a – the volumetric density of the aggregate particles [Mg/m^3] – the ratio of the mass of dry aggregate to the volume of aggregate in water together with a closed internal voids, but without voids available for water.
- ρ_{rd} – the ratio of the mass of dry aggregate to the volume of aggregate in water together with a closed internal voids, and with the voids available for water.
- ρ_{ssd} – the ratio of the mass of aggregate and the mass of water in the voids available for water to the volume of aggregate in water together with a closed internal voids and empty voids available for water.

The results are shown in Figs. 3–5. It can be seen from Fig. 3, that the bottom layer had the lowest absorbability. Each subsequent higher layer, was of the higher absorbability value than the layer beneath it. The absorbability of the top layer was of a highest value. Moreover, fine product (4-8 mm) was characterized with greater value of absorbability, compared to the coarser product (4-16 mm).

There can be also observed differences with the densities of products within individual layers. As expected, the bottom layers were of a greatest densities, while the particles that reported to the top layers had the lowest density. What might be interesting is that, the differences in densities, determined in three manners, defined the above (ρ_a, ρ_{rd}, ρ_{ssd}), can be also observed. The most significant differences were registered for the density ρ_{rd}, defined as the ratio of the mass of dry aggregate to the volume of aggregate in water together with a closed internal voids, and with the voids available for water. These differences are more significant for the coarser material (4-16 mm).

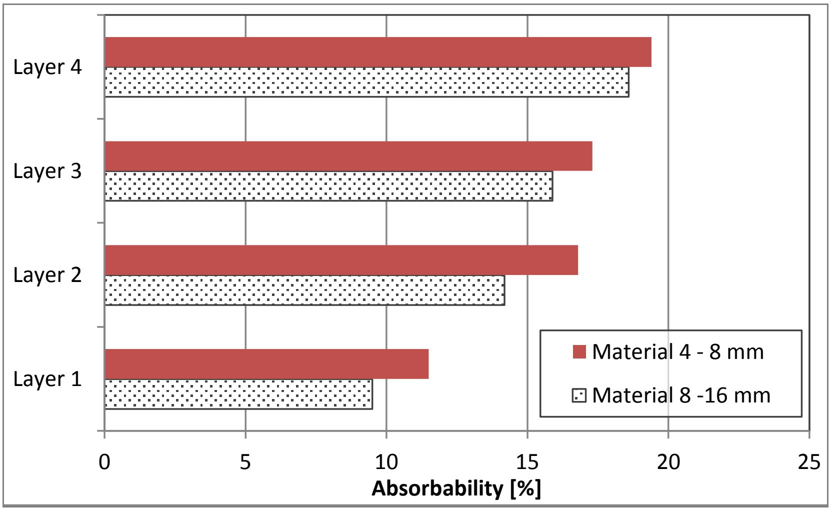

Fig. 3. Density [Mg/m^3] of chalcedonite material in individual layers in a jig

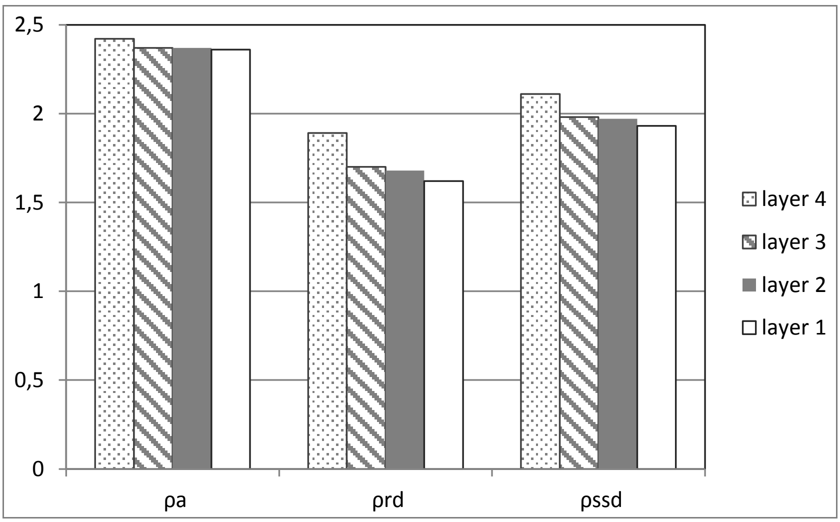

Fig. 4. Density [Mg/m^3] for chalcedonite material 4-8 mm

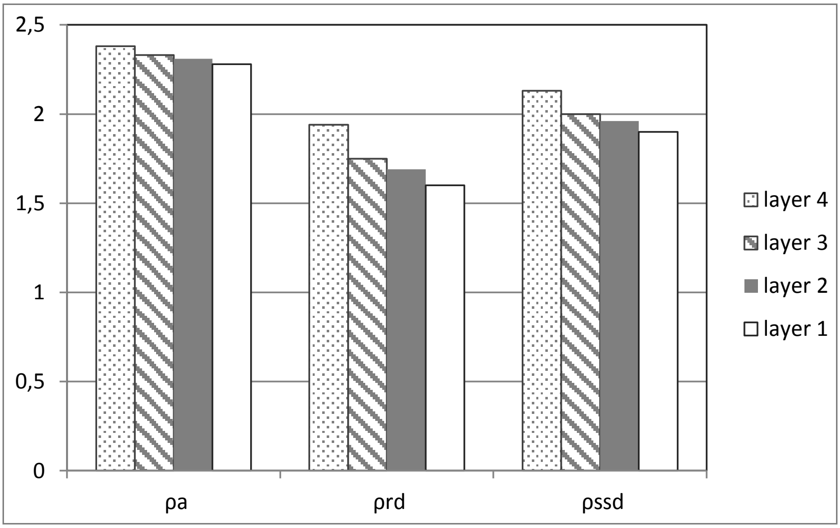

Fig. 5. Density [Mg/m^3] for chalcedonite material 8-16 mm

In the second stage of investigative programme, the separation tests for chalcedonite feed material with particle size composition from 8-31.5 mm, were carried out.

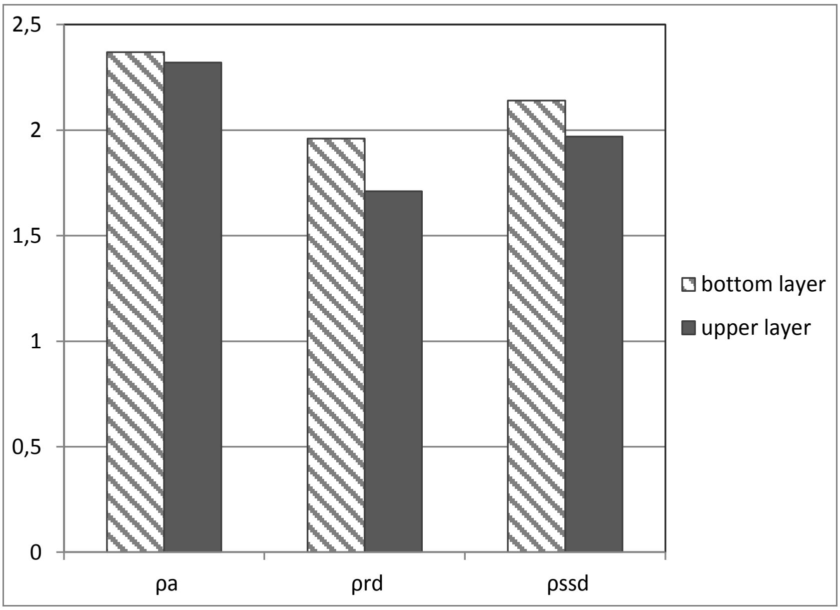

Fig. 6. Density of chalcedonite product 8-31.5 mm

This time, the product from the jig was divided into two layers: upper product, consisting of aggregate particles with lower density and the bottom one, where aggregate particles with greater density could be found. The results of separation are shown in Fig. 6, while the absorbability test results are shown in Fig. 7. Separation results show that particles in the lower layer have higher density and lower absorbability. These characteristics are true for three types of determined densities.

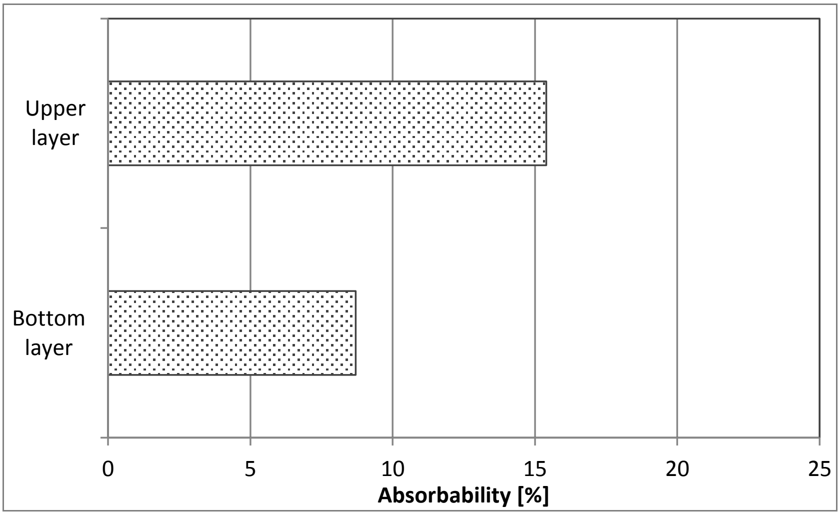

Fig. 7. Water absorption of chalcedonite product 8-31.5 mm

In the third stage of testing programme, further separation of the previously obtained products, was carried out. Each separation product obtained in the jig for 8–31.5 mm chalcedonite feed material, was underwent further separation by Dense Media Separation device (DMS), with heavy liquid density 1.98 Mg/m^3, in order to be able to assess the efficiency of the upstream process of jig separation. The scheme of investigations are seen in Fig. 8.

For both layers of the jig separation process, the yields of particles above and below the density of 1.98 Mg/m^3, were determined. The upper layer contained 13.4% of particles with density above the 1.98 Mg/m^3, while the remaining 86.6% constituted the particles with density lower that 1.98 Mg/m^3. An opposite situation was observed in the bottom layer, where the heavy particles (i.e. with the density greater than 1.98 Mg/m^3), constituted nearly three quarters (73.2%), while the remaining 26.8% were the particles with density lower than 1.98 Mg/m^3. Separation efficiency was higher in the upper layer of material, because only 13.4% of particles heavier that the heavy liquid density, were in the floating (light) product of DMS. The separation efficiency obtained for the bottom layer, in turn, was more than 10% lower comparing with the one, achieved for the upper layer. It can be improved, however, through directing for separation the material with narrow particle size fractions.

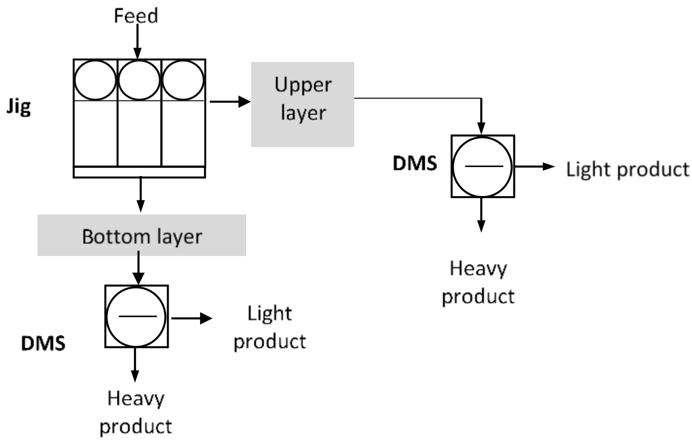

Fig. 8. Scheme of investigations for chalcedonite material 8-31.5 mm

Figure 9 shows density of chalcedonite aggregate separated in dense media separation, for heavy liquid density 1.98 Mg/m^3. Differences in densities between individual products can be seen, while the most significant difference can be also observed for the density ρ_{rd}.

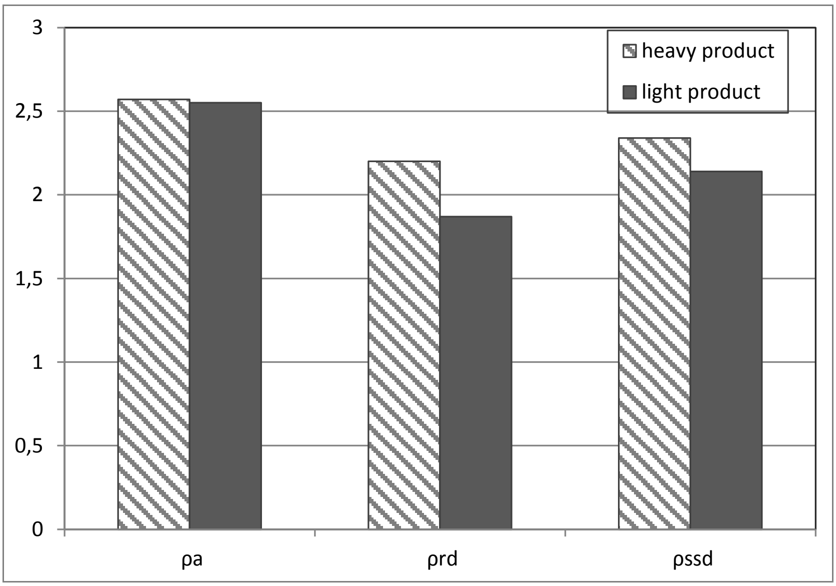

Fig. 9. Density of chalcedonite aggregate separated in DMS with heavy liquid 1.98 [Mg/m^3]

Aggregates separated in DMS were characterized by significant differences in water absorption, and high variability of strength parameters. The light product water absorption was 14.6%, while the same value for the heavy product was 6.3%. In abrasion resistance tests of micro Deval the MDE = 58% for lightweight aggregate, and MDE = 22% for heavy one (the bottom layer).

5. SUMMARY AND CONCLUSIONS

Chalcedonite is a unique silica rock, of multi-purpose utilization in the production of building materials and environmental protection. It is particularly suitable for the production of grit filter and as a component of sets of raw materials feed in firing process (lightweight aggregate and cement clinker production). Due to the high variability in chalcedonite rock density and water absorption, application of density separation process may result in obtaining the products with different physical properties but less stable density and water absorption properties.

The results of investigations presented in the paper show that, to some extent, it might be possible to overcome the above problems and through selection of appropriate parameters of separation course for more effective processing of chalcedonite can be possible. It is especially connected with the application of density separation in technological circuits of chalcedonite treatment and processing. Application of density separation process showed that this type of separation method could be beneficial for chalcedonite material. Test results showed that separation efficiency was between 73.2 and 86.6%, depending the layer. Since density separation products show lower variation in selected qualitative parameters, it creates potentials for their effective utilization, and will help in more sustainable management of this unique raw material.

REFERENCES

GARBACIK A., 2005, *Określenie przydatności chalcedonitu „Mikrosil" jako surowca krzemonośnego do produkcji klinkieru portlandzkiego w Cementowni Rudniki*, Praca IMMB Kraków.

GÓRALCZYK S. et al., 2009, *Próba półtechniczna wytworzenia sztucznego kruszywa lekkiego z osadów ściekowych i odpadów mineralnych*, Prace Naukowe Instytutu Górnictwa Politechniki Wrocławskiej Nr 125, Seria Studia i Materiały Nr 35, Górnictwo i Geologia XI, Wrocław 2009.

KOSK I., 2008, Wpływ zróżnicowania chalcedonitów ze złoża Teofilów nad Pilicą na ich walory surowcowe, Rozprawa doktorska, Uniwersytet Śląski, Gliwice.

KOSK I. 2010, *Kompleksowe zagospodarowanie odpadowych surowców chalcedonitowych z osadników kopalni „Inowłódz" w ochronie środowiska oraz w przemyśle materiałów budowlanych*, Gospodarka Surowcami Mineralnymi, t. 26, z. 1, Kraków 2010.

MICHEL M., 2011, *Charakterystyka chalcedonitu ze złoża Teofilów pod katem możliwości wykorzystania w technologii uzdatniania wody i oczyszczania ścieków*, Gospodarka Surowcami Mineralnymi. PAN, t. 27, z. 1, Kraków 2011.

NAZIEMIEC Z., 2011, *Turbopłukanie*, Surowce i Maszyny Budowlane, nr 5/2011.

NAZIEMIEC Z. et al., 2015, *Wykorzystanie oczyszczonych drobnych frakcji chalcedonitu z Kopalni „Inowłódz" w przemyśle ceramiki i materiałów budowlanych*, Praca statutowa IciMB, Kraków.

Raport Końcowy. Projekt celowy nr 7 7668 C/1969, 1997, *Kompleksowe zagospodarowanie i racjonalne wykorzystanie surowca ze złoża „Teofilów" ze szczególnym uwzględnieniem ochrony środowiska*, IMMB, Kraków.

RATAJCZAK T., WYSZOMIRSKI P., 1991, *Charakterystyka mineralogiczno surowcowa chalcedonitów spongliolitowych z Teofilowa nad Pilicą*, Gospodarka Surowcami Mineralnymi, t. 7, z. 1.

ŁAGOWSKI J., SARAMAK D., 2017, *Zastosowanie płuczek wysokociśnieniowych w procesie płukania kruszyw żwirowych*. Konferencja „Kruszywa Mineralne 2017, Kudowa Zdrój, 23–25 kwietnia.

TCHÓRZEWSKA D. et al., 1995, *Racjonalne wykorzystanie unikalnych złóż surowcowych*, Cement Wapno Gips, 2, pp. 55–57.

TCHÓRZEWSKA D. et al., 2001, *Nowe zastosowania chalcedonitu jako sorbentu w procesie oczyszczania wód*, Przegląd Geologiczny, Vol. 49, Kraków.

PN-EN 1097-6:2013. *Badania mechanicznych i fizycznych właściwości kruszyw*. Część 6, *Oznaczanie gęstości ziarn i nasiąkliwości*.