

UTILIZATION OF CONSTRUCTION WASTE AS RAW MATERIAL IN MANUFACTURING OF GYPSUM-BASED COMPOSITES

Teodora Tinkova, Georgi Paraskov, Irena Grigorova, Ivan Nishkov

University of Mining and Geology "St. Ivan Rilski", Department of Mineral Processing and
Recycling, 1700 Sofia, Bulgaria

Abstract

This paper presents a laboratory investigation of new application opportunity of building waste materials and potential usage as a component in production of gypsum based building materials. Production of new type eco-friendly gypsum based composites was studied as a potential utilisation sector. The main focus is directed on gypsum binder mixture properties examination with different proportion of incorporated construction waste materials 5-45%. It was designed and tested fresh state behaviour of gypsum-waste mixture and specimens in standard water/binder ratio. Construction waste material is a fines obtained by combined crushing-sorting installations. Slump flow test of gypsum-waste suspension and dry samples characteristics as compressive and flexural strength, water absorption and shrinkage were tested. On the basis of the obtained results, it was established that the prepared gypsum-waste mixture is an alternative for the production of gypsum based building products. Using the tested mixture in manufacturing processes lead to reduction in the energy and water consumption.

Key words: building waste, composite, sustainability, gypsum

1. INTRODUCTION

Building industry has considerable environmental impacts in every stage, from raw materials mining, through production processes, including waste generation, transport and environmental impacts in all products life cycle including the deposits. Eco-efficiency model encourages improvements on all levels and competent pollution control. On the one hand, it should be used alternative raw material which application in production of building materials would meet the market demand on the other hand it should have capacity to reduce the intensive energy and water consumption, and CO₂ footprint, which will increase production processes efficiency.

One of the most significant problems is natural raw materials usage as main resource in building materials manufacturing. Innovative approaches in environmental protection strategy require reusing, recycling and setting up of symbiosis between construction and other industries. In gypsum composites production, such practice has found expression in basic raw material replacement - gypsum with its synthetic forms (desulfogypsum, fluorogypsum, borogypsum, phosphogypsum) obtained in processes of acids production, flue gases desulphurization and ore beneficiation (Eisele, 2003; Hansen, 2009). The purpose of conceptual approach is obstruction of natural minerals depletion and industrial waste prevention. Each year building waste amount is growing rapidly. In 2010 within the European Union the total building wastes amount is about 34% of waste generation (Eurostat, 2010), obtained by construction renovation and demolition.

There are a number of studies on the construction waste products potential application, but based on the broad range of components their incorporation in composite matrix is a complex process. However, in some countries more than 90% of the waste is utilized in road construction as a sub-base (Hendriks & Ianssen 2001; Fen Ye et. al, 2009). Normally, fine waste fractions obtained from crushing, grinding and classification processes may not be applied in construction. It has been studied reuse possibility of waste through their inclusion in the composition of gypsum based building materials (Rivera et. al., 2012; Serna et. al., 2012). Gypsum materials manufacturing process, respectively gypsum granulometric preparation and its calcination are energy intensive.

The objective of this study is to reduce the calcium sulfate hemihydrate content needed for building materials manufacturing by gypsum binder replacement in mix composition with fine construction waste filler. The purpose of this study is to investigate the application potential of construction waste in designing of new gypsum composite material. It was determined advisability usage of waste materials by examining the influence on the main properties of prepared plaster samples, in order to disclose the relationships between increasing amount of inert material in mix design, its structure and properties of set gypsum bodies.

2. EXPERIMENTAL

2.1. Materials and Methods

All tests were conducted under laboratory conditions. The materials used to perform the experiments are calcined desulfogypsum ($\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$) and mixed sample of building waste materials (BWM), received as fines of mobile crushing-sorting installation. The material used as substituent of the gypsum is a multi-component mixture composed of bricks, tiles, concrete and other materials derived by demolition activities on building sites.

The main parameters of gypsum and BWM are listed in Table 1 and Table 2. Figure 1 illustrates the particle size distribution of calcium sulfate and waste material. Tests were conducted in accordance with the standards EN 13279, EN 520, EN 15283 and ASTM adapted test methods.

2.2. Sample preparation

The mix suspension was prepared with standard water binder ratio of 0.70. It was explored different percent ratio of $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$ – BWM paste as a factor having impact on the gypsum bodies mechanical behaviour under short term static and dynamic loads determined by Zwick Roell Z010 by three-point bending test. Flexural strength, calculated according to breaking load, allows to assessing the influence of higher amount added waste material.

The pastes were molded into prisms 40 x 40 x 160 mm, for flexural and compressive strength tests and cubes for water absorption. All prepared samples were kept in the mould in constant temperature for 24 h. After gypsum bodies demoulding they were cured in ambient environment for 7 days in constant temperature and humidity. After that, the specimens were dried to constant mass in dryer and were conditioned in a desiccator to achieve the room temperature before being tested.

Three samples were tested for each experiment and average value was calculated. Suspension flowability was determined by Southard viscometer. Samples for fire resistance test were formed at special prefabricated moulds in 45 x 12.5 x 300 mm and tested with Meker burners. Prisms 40 x 40 x 160 mm were molded for shrinkage experiments. In order to assess the flexural, compressive strength and elasticity modulus of the samples produced, prisms were tested after reached constant mass and conditioned in desiccator. Same sequence was used in specimens conditioning for all other prepared gypsum specimens.

Table 1. Calcium sulfate hemihydrates main characteristics

Analysis	Type	Unit	Results
1	2	3	4
Density	Bulk density	g/cm ³	0.719
	Tapped density	g/cm ³	1.128
Fineness (Blaine)		cm ² /g	4475
pH			5.99
Combined water		%	6.73
Phase content	CaSO ₄	%	0.43
	CaSO ₄ ·0.5H ₂ O	%	88.78
	CaSO ₄ (s)	%	0.43

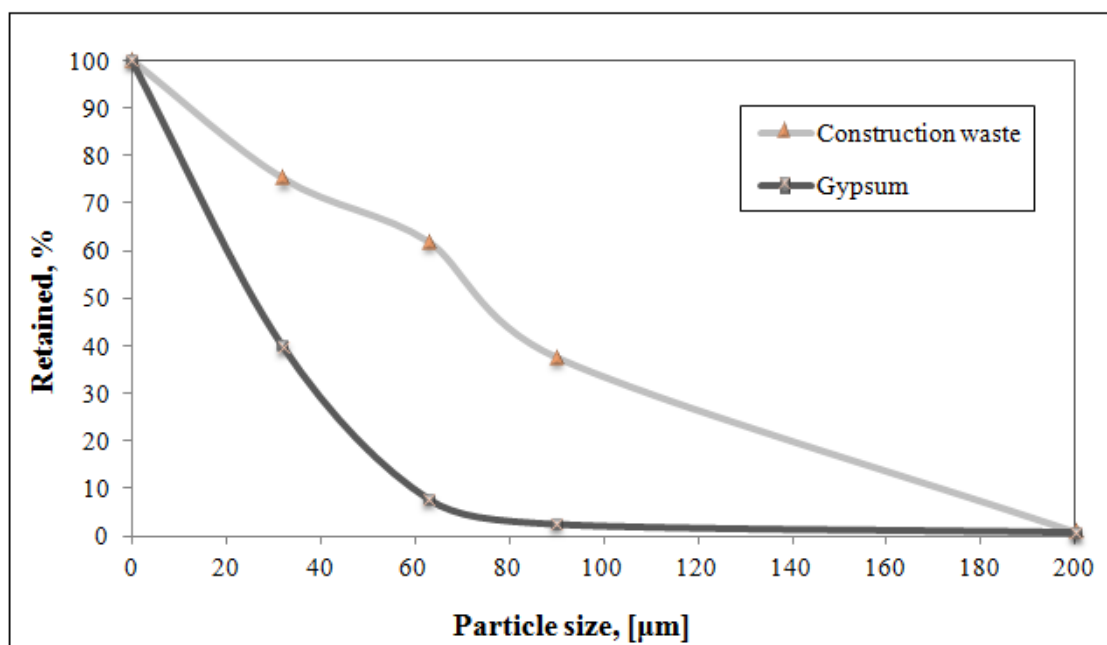


Figure 1 Particle size distribution analysis

Table 2 Construction materials powder main characteristics

Test	Density		Blaine	pH
	Bulk density	Tapped density		
1	2	3	4	5
BWM	g/cm ³	g/cm ³	cm ² /g	
	0.972	1.338	3266	10.83

2.3. Test methodology

Several series of samples were analyzed, composed by five building waste percentages by plaster weight (5%; 15%; 25%; 35%; 45%) and water/binder (w/b) ratio of 0.70 relating to 100% binder. Gypsum plaster samples without addition of waste powder (standard samples) were also elaborated in order to compare the results obtained with the rest of samples produced. Preliminary tests of fresh paste setting times (Table 3) were conducted by knife method. The second set of experimental work was directed to investigate the gypsum slurry behavior, especially its flowability for recipe with different amount of building waste. Southard viscometer was used. Figure 3 presents an increasing on mixed suspension flowability measured by Southard viscometer. The amount of waste has been changed from 5 to 45%, in increments of 10%. Increasing the amount of construction waste filler results in longer setting times of gypsum mixture. Also, it was observed improving on slurry fluidity. 15% waste material addition flow diameter rising by approximately 12%, and the sample comprised of 45% waste additive rising flow diameter more than 60%. Here it should be noted the excellent homogenization of blended mixture, due to the fineness of filler aggregates.

Table 3 Suspension setting times

Type	Unit	Standard	BWM content in the mixture, %				
			5%	15%	25%	35%	45%
1	2	3	4	5	6	7	8
Initial	min:sec	01:50	01:50	01:55	01:55	02:00	02:30
Final	min:sec	05:30	05:30	05:50	06:10	06:10	07:05

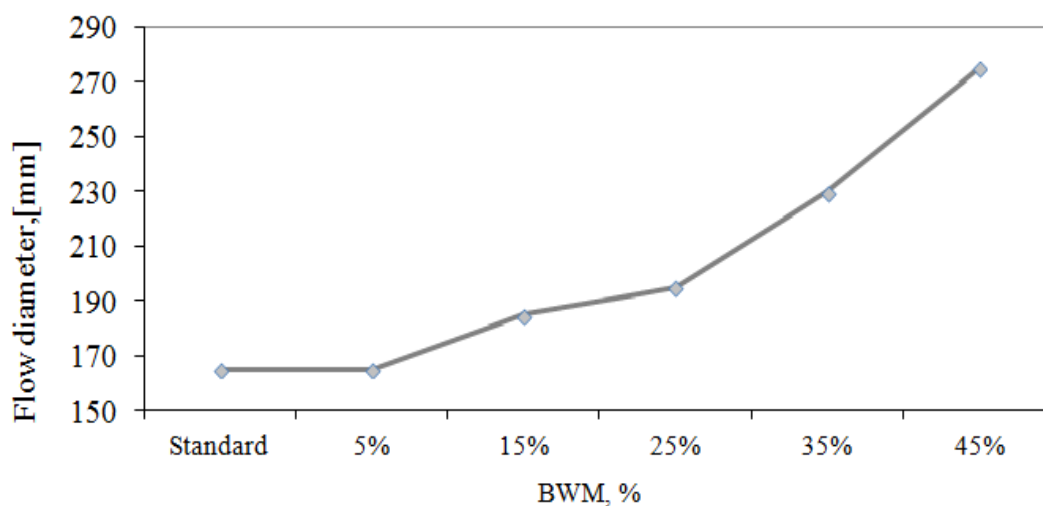


Figure 2 Slump flow test determined by Southard viscometer

3. RESULTS AND DISCUSSIONS

3.1. Strength-deformation characteristics

It could be said that the increasing the amount of waste material decreases strength of the samples (Fig. 3). Compressive strength and flexural strength tests were conducted, and based on the results obtained it can be concluded that both the test showed a similar trend in strength reduction of tested samples. Mechanical behavior of most mixed cementitious materials extremely depends of the type,

quantity and particles size of additives. It could be explained by the Griffiths crack theory that materials have primary, randomly oriented micro-cracks. Under the external forces influence on the top or near of these micro-cracks there are concentrated tensions that caused cracks propagation and led to the materials breakage. That makes easier transmitting of surface emerging tensions and rapidly cracks dissolving into body matrix, which results on lower structure entirety retention. At composite plastic period the elasticity modulus is preserving even in higher rate of additive. Nevertheless, it could be said that the process of micro-cracks formation occurs very quickly, which result on macro-cracks opening so an important strength loss is observed when increasing the construction material addition.

Compressive strength test results of samples with 45% waste material content were 8.3 N/mm² and flexural strength was 2.27 N/mm². Compared to the reference sample that means, compressive strength decreases with almost 61%, and flexural strength decreases with 59%. Samples containing 25% of waste powder shows decreasing of flexural strength values with 27% to 4.02 N/mm² and compressive strength reduction with 33%, reaching 14.3 N/mm².

This is probably due to the reduction of hemihydrate amount and the constant amount of added water. That means the behavior of tensile load is determined by the water excess. The smaller quantity of hemihydrate refers to the less dihydrate crystals formation, which results in reduction of crystals contact points. Especially if it is taking into account that the waste material added do not have setting properties.

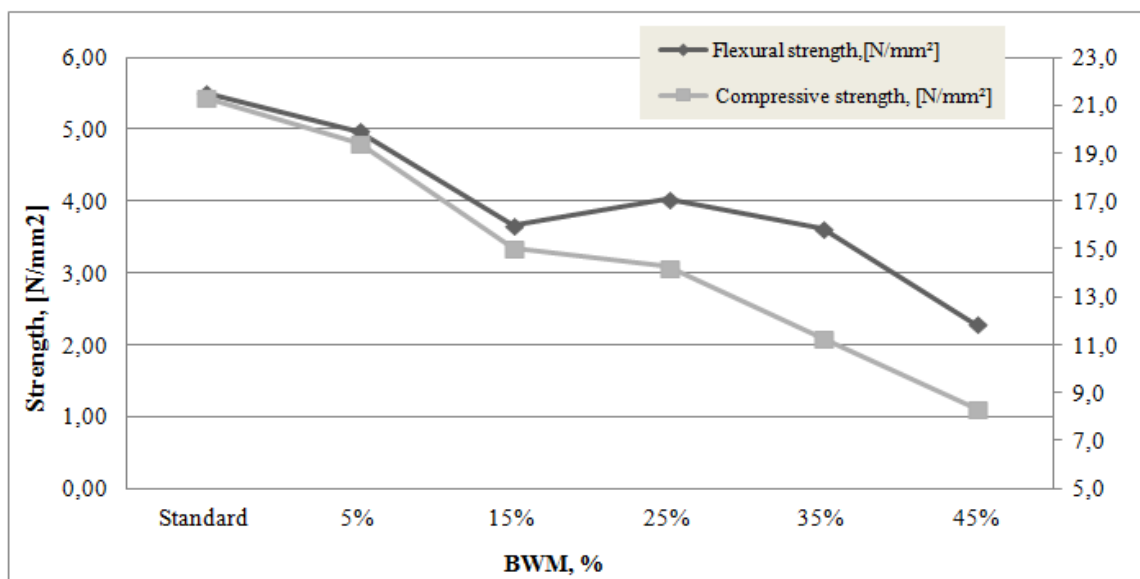


Figure 3 Mechanical properties of set composite prisms

3.2. Shrinkage

There is no standard methodology of plaster shrinkage determination. However, the treatment time and the temperature are extremely important parameters. We choose two temperature levels of 750°C and 930°C in heating time of 20min. (Fig. 4).

When a small amount of waste is added there is a significant increase in the shrinkage. Figure 5 illustrates specimen shrinkage changes according to the different amount of construction waste addition. The waste powder influence occurs with increasing its rate into the mixture. It was observed markedly decreasing overall shrinkage of tested samples. Here it should be noted that the mixed sample of waste materials contains some amount of tiles, bricks and ceramic tiles. Probably the specificity of the constituent components determines the total shrinkage reduction of the tested prisms.

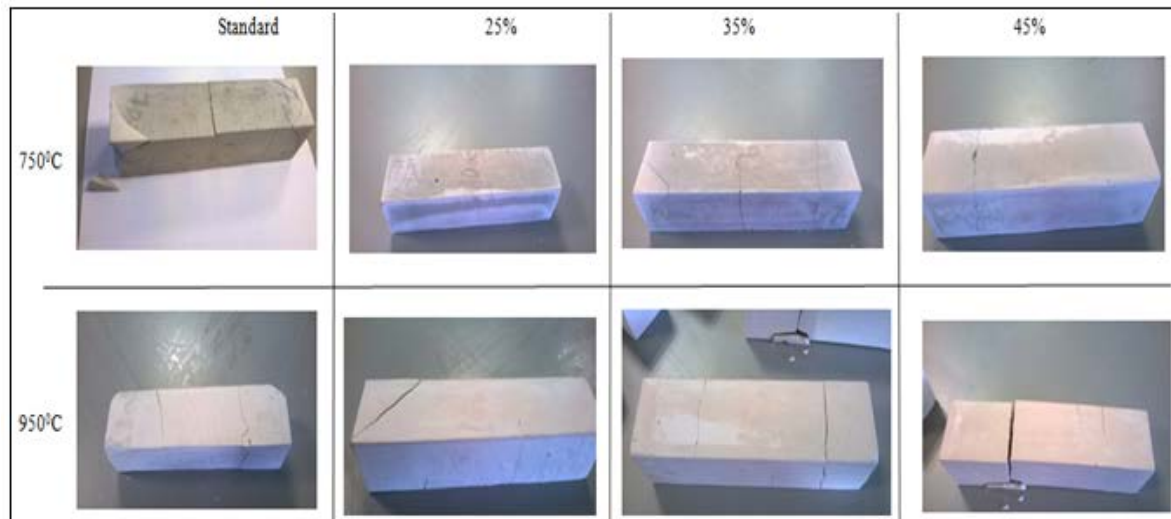


Figure 4 Samples shrinkage and cracks formation

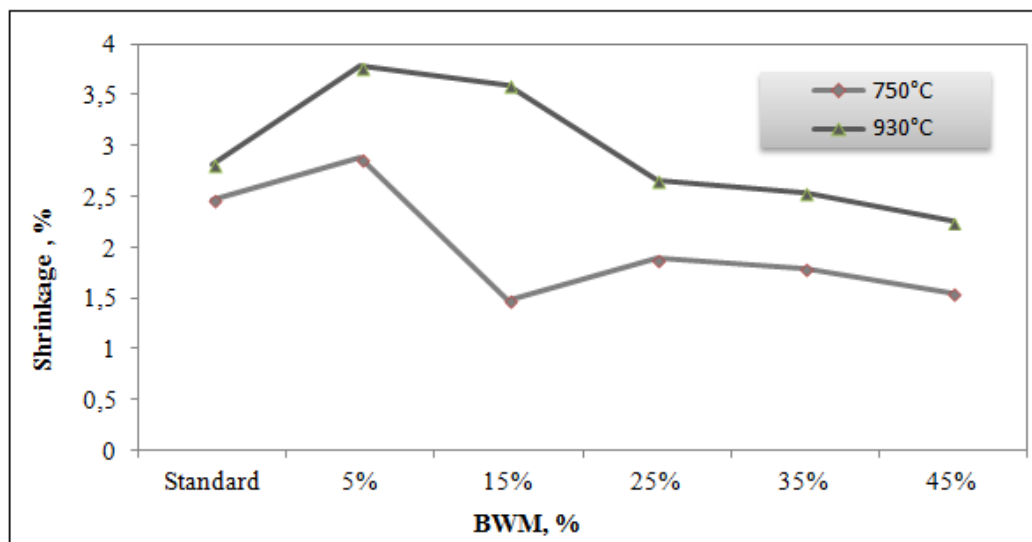


Figure 5 Samples shrinkage results at different percentage of construction waste, %

3.3. Core cohesion

The blended multicomponent aggregate, also referred to fire resistance improvement, and has successful performance on gypsum composite optimization. Fire resistance is a very important construction materials property, so it was studied a series of specially molded specimens 45 x 12.5 x 300 mm, burned by Meker burners fulfilling standard EN 520.

Sample containing 45% additive test results shows almost doubled increasing of fire resistance referred to standard samples. To perform satisfactorily results if exposed to fire the units should have more than 30% of BWM powder.

Table 4 Core cohesion results at different percentage of construction waste, (min:sec)

Sample	Unit	Reusult	Results				
			BWM content in the samples, %				
Standard	min:sec	00:04	5%	15%	25%	35%	45%
BWM	min:sec		00:05	00:19	00:36	00:51	01:18

3.4. Water absorption

It was tested composite produced in relation to its absorption properties. The results show that the increases of inert material by 10%, increases the water absorption with an average of 1.5%. Samples containing 45% of waste have 5% higher water absorption compared to the standard sample. Inert materials addition affects negatively on prepared bodies water absorption.

CONCLUSIONS

Our purpose was to be created scientific and practicable preconditions of material usage in manufacturing of gypsum based green products. Based on the result obtained and changes observed the following few conclusions are summarized:

- The suspension flowability increasing up to 5% BWM content. With increasing the amount more than 15%, better flowability is observed. The lower binder content in the mixture allows to water reduction in production process.
- Recipes with higher amount of BWM result in slight increasing of setting time. The changes are not so serious to cause some negative effects in the production of plaster based products.
- The composite bodies show better fire resistance properties than the standard sample.
- Flexural and compressive strength decreases generally with increasing the BWM content in the bodies. Samples with 25% BWM show still acceptable values.
- It was observed shrinkage reduction of gypsum samples at high waste content.
- The increase of BWM content in the recipes result in deterioration of water absorption properties of the set gypsum samples.
- It was found potential application of fines from crushing-sorting installations of construction waste granulometric preparation.
- Usually fines of BWM are not applicable in the industry, but incorporated into gypsum composite structure is an excellent substitute of calcium sulfate hemihydrates.
- Building waste materials incorporating into gypsum composites products in amount of 15% to 30%, would facilitate their disposal and turn gypsum industry into well-established utilization sector. Pre-beneficiation is not required. The use would reduce maximum energy consumption, respectively production costs. As the hemihydrate fraction decreases, the construction waste material fraction increases, therefore, gypsum composite sustainability and cost, will all be improved. On the other hand, flowability increasing has the potential to reduce water consumption and energy for drying the product. Distancing from traditional reusing practices, it could be said that production of green composites is an excellent opportunity of construction waste utilization.

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