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RECYCLED AGGREGATE AND THE METHOD OF MECHANICAL ACTIVATION

K. Hercigová[1], Karel Šeps[2]

[1,2]*Czech Technical University in Prague, Czech Republic*

ABSTRACT

This paper is a literature review on topic of recycled aggregate (RA) and mechanical activation method (MA). Basic recommendations for utilization of RA are summarized and examples of successful application of RA in road structures are presented. A method of MA is presented as well. This method can be utilized as secondary treatment for selected materials, especially concrete mix compounds.

Keywords: Mechanical Activation, Recycled Aggregate

I. INTRODUCTION

Concrete is nowadays the most common building material for roads, buildings, bridges and other infrastructure [1]. In average, approximately 1 ton of concrete per capita is produced every year [1, 2]. Alarming reality is that sooner or later this volume is going to become a waste. In 2010 in countries of the European Union Construction and Demolition Waste (CDW) represents one third of entire waste production [3]. To act in line with sustainable development in certain areas, natural material is being partly or completely replaced by CDW. However, apart from the waste issue it is necessary to realize that for 1 ton of concrete 300 – 450 kg of cement is necessary. Unfortunately, cement is one of the materials with highest embodied CO2 emissions [1]. Cement industry is responsible for 5 – 7 % of anthropogenic carbon dioxide production [1, 2]. Therefore, there is global trend to develop so-called "green concrete" where in general cement is partially replaced by another material with lower embodied CO_2 emissions in comparison with other materials [2]. To deal with mentioned issues, there is an effort to re-use CDW in civil engineering again. Concrete waste is being used in the form of recycled aggregate (RA), other waste such as fly ash or granite powder are being used as concrete additives.

Unfortunately, current trend in utilization of recycled aggregate is rather "down-cycling" – material which originally had high quality is re-used for inferior purposes. This is not very efficient, therefore there are several research programs which try to prove quality of recycled materials and also studies which try to find better way of re-use of high-quality waste. In this paper, current knowledge about usage of recycled aggregate and few examples of good employment of RA are captured. The method of Mechanical Activation (MA), which may enable re-usage of concrete waste as cement replacement, is presented as well.

II. RECYCLED AGGREGATE AND ITS EMPLOYMENT IN ROAD INFRASTRUCTURE

Recycled Aggregate (RA) is gained from concrete waste by a process of several treatments. Blocks of material are crushed and reinforcement is separated. As a result, coarse and fine aggregate is obtained. The utilization of both components is limited and differs one from the other. Results from several studies are captured below.

The road constructions are suitable for utilization of RA for two main reasons. Firstly, road constructions represent huge volume and therefore it is possible to use large volume of RA. Secondly, the road reconstructions are great opportunity to recycle and re-use the material in-situ. Avoiding transportation is a benefit to environment and it means cost savings as well. Several possible employments of the RA can be found in road construction. RA or CDW in general is widely used in subgrade layer (Fig. 1), however for RA this is an example of down-cycling. In foreign countries there are several examples of utilization of RA in subbase course which means better evaluation of RA [4].

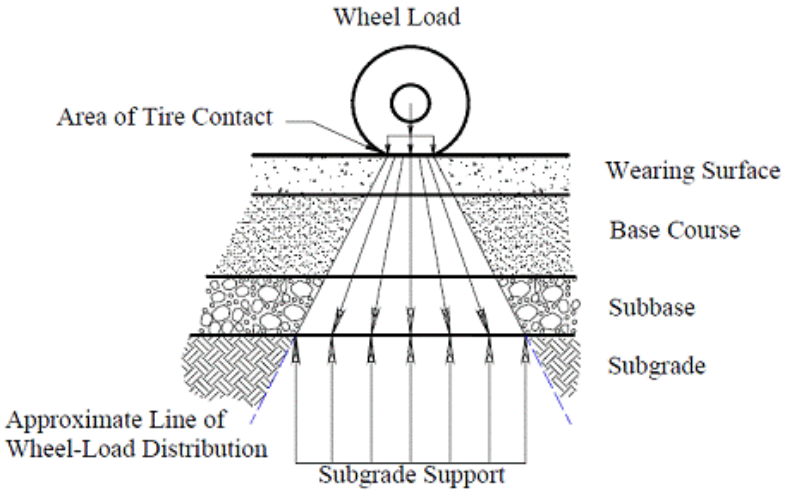

Figure 1: Road Structure Profile [5]

The recycled aggregate can be further divided into two parts – coarse and fine aggregate. In general, concrete with recycled aggregate has worse rheological performance. This is a result of higher water-cement ratio which is needed if RA is used (compared to natural aggregate). The necessity of higher w/c ratio is caused by the rests on cement paste remaining on coarse aggregates. Also the presence of fine component raises the necessary volume of batch water. As these factors lead to worsen quality, several studies have been conducted and several rules or recommendation to utilization of RA were formulated.

A research from Great Britain shows that there is significant difference between replacement of fine recycled aggregate (FRA) and coarse recycled aggregate (CRA). From the results displayed in Fig. 2, it is obvious that natural aggregate (NA) can be replaced up to 60 % by CRA without important impact on the compressive strength. However, FRA noticeably influences the strength already in case of 20 % replacement NA by FRA. It has been proven as well that crushed bricks have very negative impact on final mechanical characteristics. Therefore its volume should be restricted to 10 % maximum [6].

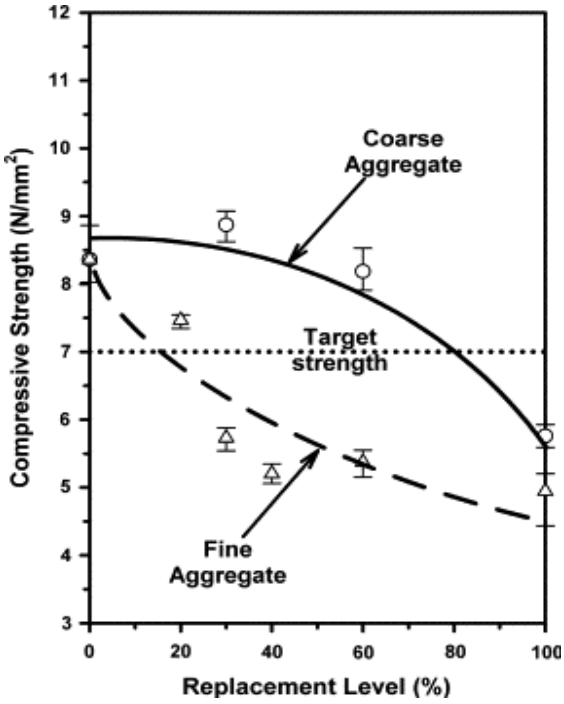

Figure 2: Replacement of natural aggregate by fine and coarse recycled aggregate (adopted from [6])

Since the worsen quality of concrete mix with RA is caused by cement paste remaining on surface of the aggregate, it is possible to improve the quality by secondary treatment of RA. The aim of such treatment is to remove the remaining cement paste from the surface of RA. There are several methods which can be used [7]:

- Mechanical removal by abrasion
- Combination of mechanical and thermal treatment
- Electrodynamic or electrohydraulic methods

Detailed description of methods can be found in cited literature. Other treatments are described in other papers, for example "two stage mixing approach" [8] and others.

III. EXAMPLES OF EMPLOYMENT OF RECYCLED AGGREGATE IN ROAD STRUCTURES

In some countries, recycled aggregate has been successfully used in upper layers of concrete road structure. That shows that it is possible to meaningfully utilize RA.

An interesting example is reconstruction of A1 highway in Austria, where 100 % of material was re-used in new road structure. Material from old surface was treated, washed out of fine particles and sorted into several fractions (Fig. 3). These fractures were stored near to the site and used later to cement stabilized foundation slab and subbase concrete. Recycling in-situ saved 1,7 million km of heavy transportation and it prevented production of 1445 ton of carbon dioxide [9].

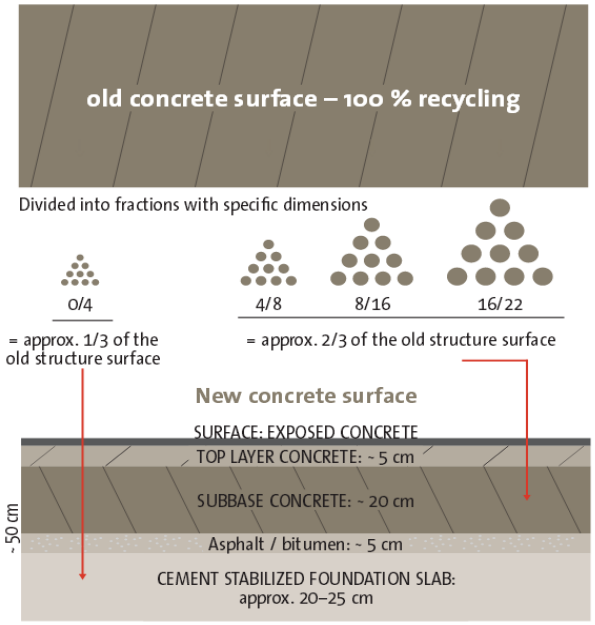

Figure 3: Utilization of recycled aggregate in road profile of highway A1 in Austria (adopted from [9])

In Nordic countries they focus a lot on research of utilization of recycled aggregate in road structures. In 2004, RA has been introduced in their national construction standard for road structures as construction material. Many realized projects proved that employment of recycled concrete is suitable solution for road structures, despite the fact that the material often does not accomplish the requirement of mechanical strength. Traditional testing methods are not convenient for this type of material, correct evaluation should be done according to methods respecting functional behavior of material.

A specific project has been realized in Norway. Trial section has been built between years 2003 and 2004 as a part of highway E6 in Melhus close to Trondheim. The highway is the main connection line between the south-east and the north of Norway, therefore it needs to support heavy traffic (ATD = 12 500). Crused concrete of two different fractions 0/100 mm and 20/100 mm has been used into sub-base structure of asphalt pavement. The recycled material came from eliminated prefabricated concrete panels, thus had high quality.

Figure 4: Material for recycling (adopted from [10])

Figure 5: Paving (adopted from [10])

The structure has been monitored during the construction and after finalization as well and an increase of modulus of elasticity has been observed. From initial values E = 350 – 650 MPa (higher values are for fraction 20/100 mm) after one year and half of operation of the trial section of E6 highway, the modulus of elasticity grew almost twice E = 800 – 900 MPa (fraction 0/100 mm, values has been calculated retrospectively out of data from measurements of specimens executed by deflectometer FWD). High elastic stiffness values compared to natural material (ordinary gravel or crushed rock material) has been observed as well [10, 11, 12].

IV. THE METHOD OF MECHANICAL ACTIVATION

The method of Mechanical Activation (MA) is a way of secondary treatment of materials. This method resides in mechanical crushing of materials. The effect is that more fine material with higher specific volume is gained. This increase of specific volume (meaning also fineness) has direct impact on reactivity of the material. Since the surface area is significantly increased, larger surface is open to chemical reactions. This consideration can be justified on behaviour of cement. Cement's specific surface is in the range from 250 to 600 m^2/kg. It is well known that cement with higher specific surface hydrates faster and better than more rough cement.

On example of coarse raw fly ash particle (Fig. 6) it is possible to observe positive impact of MA. By grinding, smaller reactive particles and smaller less reactive particles are obtained. Smaller reactive particles can better react in chemical reactions, less reactive ones can become a good filler between cement particles.

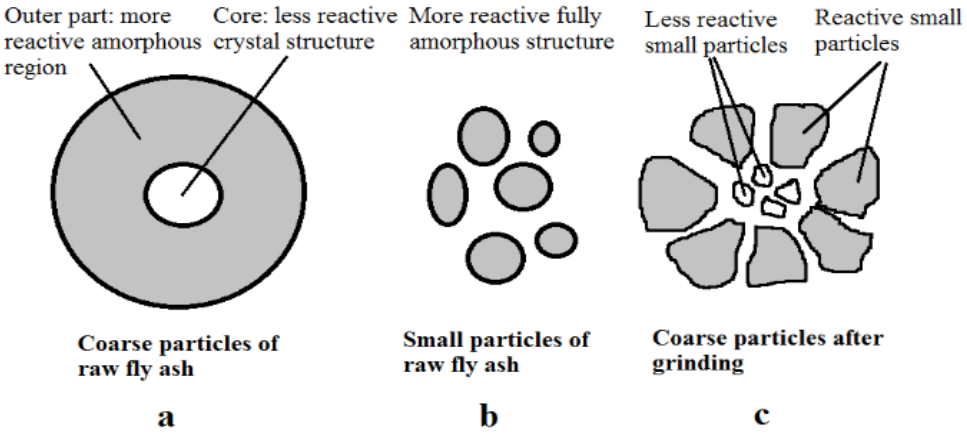

Figure 6: Process of Grinding (adopted from [13])

However, higher specific volume brings along some less positive effects as higher w/c ratio while preserving consistency. Unfortunately, higher w/c ration has in general unfavourable impact. Therefore, the best balance between all aspects always needs to be found. , In research regarding MA of fly ash from Czech authors [13], the fineness close to the cement fineness (250 – 600 m2/kg) has been defined as the most convenient one.

Result of MA strongly depends on type of the mill as well as on speed and duration of milling. There are various types of mills – hammer mill, ball mill, attritor mill, jet mill etc., Fig. 7. They differ in the mean of grinding. Detailed analysis on economical effectiveness could prove its different rating, but this is not a subject of this article. The majority of mills use some milling medium – hammers, balls; Medium is placed together with the initial material in a roller or another convenient container. The medium or entire container is then set in motion and the collision of milling medium causes crushing of the material. It is necessary to invest adequate power to

actually cause the crushing. That is the condition of speed and grinding time and it highly depends on specific mill and material. As an example, research concerning mechanical activation of granite powder can be taken. The sample of granite powder grinded for 10 minutes with 350 revolutions per minute did not achieve the activation; the sample grinded for 60 minutes with 600 revolutions per minute was activated [13, 14].

Several experiments related to this issue were already conducted in different parts of the world. In general it is possible to observe that all of them have proven a positive impact of MA treatment on additions such as granite powder, slag or fly ash. In comparison with reference specimens containing non-treated addition, specimens with MA addition achieved higher both early age and final strength. The Young's modulus of elasticity has not been evaluated within these experiments [4].

The method of MA seems to be a suitable solution for secondary treatment of recycled aggregate as well. There is a hypothesis, that mechanically activated recycled aggregate could be used as partial cement replacement in concrete recipe. This will be an objective of further research in Czech Technical University in Prague.

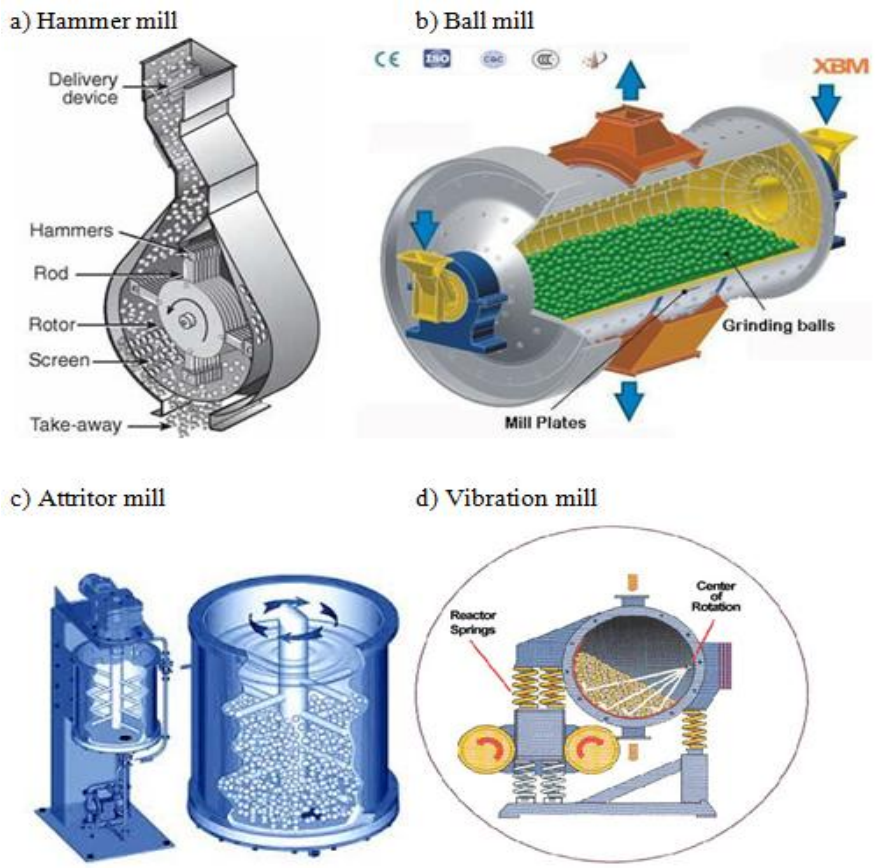

Figure 7: Mill types (adopted from [4])

V. CONCLUSION

The utilization of construction and demolition waste (CDW) is necessary in order to behave in line with sustainable development. Nowadays construction CDW is not utilized as it could be. Recycled materials are used mainly for "down-cycling", however there are already some flagships proving that meaningful employment of good quality recycled material is possible. CDW is currently used in the form of recycled

aggregate (RA). It is necessary to make difference between fine and coarse recycled aggregate (FRA and CRA). While CRA can replace up to 60% of natural aggregate without important impact on final strength of concrete, FRA negatively influences final strengths already in small volume (20 % replacement). Mechanical characteristics of concrete with RA can be improved by several treatment methods which lead to reduction of cement paste remaining on surface of the aggregate which is the source of worsen mechanical characteristics.

The method of mechanical activation (MA) means other possible option for employment of CDW/RA in concrete recipe. MA is a secondary treatment method which crushes material into fine ash with high specific volume. The possibility to use the material (RA) treated by this method as partial cement replacement will be an objective of further research in Czech Technical University in Prague.

VI. ACKNOWLEDGEMENT

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REFERENCES

[1] P. Van Den Heede, N. De Belie, Environmental impact and life cycle assessment (LCA) of traditional and 'green' concretes: Literature review and theoretical calculations, Cement and Concrete Composites 34, (2014) 431- 442, http://dx.doi.org/10.1016/j.cemconcomp.2012.01.004.

[2] D. N. Huntzinger, T. D. Eatmont, A life-cycle assessment of Portland cement manufacturing: comparing the traditional process with alternative technologies, Jurnal of cleaner production 17, (2009) 668 – 675, http://dx.doi.org/10.1016/j.jclepro.2008.04.007.

[3] Wastestatistics, Statistics Explained (2013), Retrieved from: http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Waste_statistics.

[4] K. Hercigová, Supervisor: J. Vašková, Exploitation of mechanically activated recycled concrete from transportation structures, CTU in Prague, Thesis (2014).

[5] Retrieved from: http://theconstructor.org/transportation/flexible-pavement-composition-and-structure/5499/.

[6] M. N. Soutsos, K. Tang, S. G. Millard, Concrete building blocks made with recycled demolition aggregate, Construction and Building Materials 25, (2011), 726 – 735, http://dx.doi.org/10.1016/j.conbuildmat.2010.07.014.

[7] Y. Sui, A. Mueller, Development of thermo-mechanical treatment for recycling of used concrete, Materials and Structures 45, (2015), 1487-1495, http://dx.doi.org/10.1617/s11527-012-9852-z.

[8] V. W. Y. Tam, C. M. Tam, Assessment of durability of recycled aggregate concrete produced by two-stage mixing approach, Journal of Materials Science 42, (2007), 3592 – 3602, http://dx.doi.org/10.1007/s10853-006-0379-y.

[9] Concrete recycling: The route from the old road to the modern motorway, Asamer, Retrieved from: http://www.asamer.at/sites/default/files/e_asamer0112_lowres_final.pdf.

[10] J. Aurstad, J. Aksnes, N. Dahlhaug, G. Berntsen, N. Uthus, Unbound crushed concrete in high volume roads: A field and laboratory study, http://www.sintef.no/upload/126.pdf.

[11] J. Aurstad, G. Berntsten, G. Petkovic, Evaluation of unbound crushed concrete as road building material – Mechanical properties vs field performance, http://www.vegvesen.no/_attachment/110440/binary/192535.

[12] D. Stehlík, Stavební a demoliční odpad v konstrukcích pozemních komunikacích, Časopis stavebnictví, 2008, http://www.casopisstavebnictvi.cz/clanek.php?detail=718.

[13] R. Hela, D. Orsáková, The Mechanical Activation of Fly Ash, Procedia Engineering 65, (2013) 87 – 93, http://dx.doi.org/10.1016/j.proeng.2013.09.016.

[14] P. C. Lessard, M. Havens-Cook, Mechanical Activation of Granite Rock Dust: Strength Development in Portland Cement Concrete and Lime Mortars, Journal of Metastable and Nanocrystalline Materials 13, (2001) 589 – 596, http://dx.doi.org/10.4028/www.scientific.net/JMNM.13.589 .