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## ROLLER-COMPACTED CONCRETE WITH THE USE OF RECYCLED AGGREGATE FOR LOCAL ROAD PAVEMENT EXECUTION

### BETON WAŁOWANY Z WYKORZYSTANIEM KRUSZYWA Z RECYKLINGU DO WYKONYWANIA NAWIERZCHNI DRÓG LOKALNYCH

**STRESZCZENIE.** Beton wałowany RCC jest specjalną odmianą mieszanki betonowej o optymalnej wilgotności, zbliżonej do wilgotności gruntu. Układany jest standardowym rozścielaczem asfaltowym i zagęszczany przy użyciu walców drogowych. Technologia betonu wałowanego ze względu na swoje zalety: jak szybkość realizacji i niskie koszty budowy, jest dobrym rozwiązaniem w budowie dróg lokalnych. Beton wałowany jest doskonałą i nowoczesną alternatywą dla innych mieszanek, gdzie z powodzeniem można zastosować materiały z recyklingu, zatem warto zastanowić się nad szerszym jej wykorzystaniem w budowie dróg Polsce. W artykule zostaną przedstawione wymagania dla materiałów stosowanych do produkcji betonu wałowanego, sposób wykonania nawierzchni z betonu wałowanego. Poruszone zostanie również zagadnienie wykorzystania istniejącej nawierzchni do produkcji betonu wałowanego np. gruz betonowy uzyskany z nawierzchni z płyt drogowych, destrukta asfaltowy.

**SŁOWA KLUCZOWE:** beton wałowany, beton z recyklingu, drogi lokalne.

**ABSTRACT.** Roller-compacted concrete (RCC) is a special variety of concrete mix with an optimum moisture content, close to that of the ground. It is laid with a standard asphalt paver and compacted using road rollers. Roller-compacted concrete technology is a good solution for the construction of local roads due to its advantages, such as speed of implementation and low construction costs. RCC is an excellent and modern alternative to other mixes where recycled materials can be successfully used, so it is worth considering its wider use in Poland's road construction. The paper will outline the requirements for the materials used in the production of roller-compacted concrete and the method of execution of RCC pavements. The use of existing pavement for the production of RCC, e.g. concrete rubble obtained from road slabs, Reclaimed Asphalt Pavement (RAP), will also be addressed.

**KEYWORDS:** Roller-compacted concrete, RCC, recycled concrete, local roads.

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## 1. INTRODUCTION

The first attempts to use roller-compacted concrete (RCC) were recorded in Sweden in the 1930s. However, due to difficulties in achieving a satisfactory concrete compaction rate, further use of this technology was abandoned. The return to the use of RCC came in the 1970s. The first use of RCC technology pavement on a wider scale took place in Canada, on forest tracks. Subsequently, the material became of interest to the US Army Corps of Engineers which is responsible for the construction and maintenance of facilities of military significance. Since the 1990s, RCC has attracted the interest of the automotive industry. Roller-compacted concrete has been used in process yards at Honda, Hyundai and Kia factories, as well as distribution centres, warehouses, port handling terminals (e.g. Port of Houston, Texas) or in the construction of dams. The US-Mexico border crossing at Brownsville was also executed using RCC technology [1].

At the beginning of this century, the advantages of the technology were also recognised by the road industry. Residential streets, local roads, motorway emergency lanes, border crossings or intersections were increasingly designed using RCC technology. The first RCC road in Poland was built in November 2010 and it was a 325-metre section of Fabryczna street in Miastko, Pomorskie province. The first public machine-paved road was in 2013 a 70-metre section of Sportowa street in Zaklikowo (Podkarpackie province). Further road projects using roller-compacted concrete appeared in Zabrze, Trzebinia, in the municipality of Wilkołaz, in the Częstochowa district: the Żuraw-Lusławice road, the Czepurka-Piasek road, the Chruślanki Józefowskie-Mikołajówka road (municipality of Józefów nad Wisłą), at the Iron and Colour Metals Recycling Plant in Zabrze 8094 m<sup>2</sup> (square), at the cement works in Chełm and Rudniki near Częstochowa.

In Europe, RCC roads are already common in Norway, Belgium and the UK, for example.

## 2. ROLLER-COMPACTED CONCRETE (RCC)

RCC is a classic cement concrete, but adapted only for compaction by rolling. It is a dry mix with zero slump (a method of testing the consistency of a concrete mix) with a composition similar to that of conventional concrete, but the individual components are present

in different proportions. Between 75% and even 85% of the batch volume consists of aggregates compacted in such a way as to reduce the air content of the mix and increase its density. The main differences relate to the content of dust fractions in the batch, which are not desirable in conventional concrete, while in RCC they determine the stability of the mix during compaction. The cement content is lower than in conventional concrete, but should not be less than 270 kg/m<sup>3</sup>. The water content of the mix should be determined by preliminary tests using the modified Proctor method in accordance with EN 13286 2 [2] – to determine the optimum moisture content. The water content is typically 90–120 kg/m<sup>3</sup>, which translates into a low w/c ratio (0.30–0.45) [3]. All of this is aimed at achieving the optimum moisture content, i.e. the moisture content at which the concrete will most easily be compacted:

- the composition of roller-compacted concrete should therefore be chosen so that,
- mix components with optimum moisture content did not segregate,
- the layer of freshly laid mix keeps the compaction rollers on its surface and undergoes compaction at the same time,
- the concrete lets itself to be compacted.

According to the General Technical Specification of the General Directorate for National Roads and Motorways [3], it can be used in the following cases:

- pavements not exposed to precipitation and de-icing salts – moderately used (e.g. storage yards under shelters) – made of concrete with minimum class C20/25;
- road pavements with traffic categories KR1-KR2 – made of concrete with minimum class C25/30;
- pavements of technological roads (access roads, bypass roads, service roads), internal roads, manoeuvring yards, etc. (with loads corresponding to traffic categories KR3-KR4 on national roads) – made of concrete with minimum class C30/37;
- road foundations for roads in traffic categories KR1-KR7 – according to WT5 guidelines.

Experience and test results show that RCC pavements retain a very high level of frost resistance despite the use of lower cement quantities than required by EN 206+A2:2021 [4] and the lack of aeration [5, 6, 7].

### 3. EXECUTION OF ROLLER-COMPACTED CONCRETE (RCC) PAVEMENTS

The thickness of the RCC concrete layer for KR1 category pavements should not be less than 12 cm, and should optimally reach 15 cm, as is the case on most municipal roads built in conventional concrete. A thinner layer, 10 cm, would be appropriate on cycle paths, for example. The maximum thickness of the layer to be laid depends on the parameters of the individual paver, with two-layer paving also possible.

The execution of the construction, as with classic concrete, should be carried out under certain weather conditions: the temperature of between 5°C to 25°C and no forecast rainfall (if this occurs at construction works that have already been started, the road should be covered with a waterproof membrane).

The concrete mix, once produced, is delivered to the construction site and trucks with steel semi-trailers are used for transport (concrete cannot be transported by aluminium semi-trailers). The requirement is for the concrete to be delivered to the paver within 60–90 minutes of the mix being produced, unless admixtures are used to delay the cement binding process. The mix should be transported by dump trucks under a tarpaulin, which protects the material from drying out.

The mix is then unloaded and spread with a bituminous mix paver. It should be noted that only a fraction of the asphalt pavers available on the market will work well for a concrete project due to the quality of the pavement. A suitable paver should be characterised by a high compaction table (at least 4 tonnes is preferred)

and a double row of rammers. Initial compaction behind the paver should reach a minimum of 90% and preferably 95%. It is a good idea for the contractor to be able to continuously monitor the compaction with a nuclear density gauge. With RCC being a much less plastic material than asphalt, achieving high pre-compaction is essential for the evenness of the constructed pavement.

The RCC mix should be compacted in such a way as to achieve the required compaction rate of  $I_s = 96\%$ . Compaction rollers should have a minimum weight of 8 tonnes. A proper rolling procedure is necessary to ensure uniform compaction over the entire surface of the facility, so that the edges of the pavement are compacted to the same extent as the centre.

Once the concrete has been compacted, the curing process should begin immediately. To do this, the concrete surface is coated with a white hydrophobic preparation, not forgetting to coat the side surfaces of the slabs as well.

The incision of the expansion joints is made at such a point that there is no damage to the edges in the form of chipping of the slabs and pulling of aggregate grains. Transverse expansion joint incisions are typically made at 6 m spacing for pavements less than 20 cm thick and longitudinal incisions for widths greater than 6 m. The technique for filling the joints can be twofold: hot (e.g. asphalt compound) or cold (e.g. synthetic resin mixes). Whichever technique is chosen, a sealing liner (e.g. polyethylene rope) must first be placed in the joint.

Unlike conventional concrete pavements, RCC does not require reinforcement, dowelling or anchoring.

Figure 1 shows the production process of RCC [8].



Fig. 1. Production process of RCC: a) mixing and transport, b) paving, c) compaction, d) curing [8]

#### 4. ADVANTAGES AND DISADVANTAGES OF ROLLER-COMPACTED CONCRETE (RCC) PAVEMENTS

RCC pavement combines both the advantages of asphalt roads and concrete roads made using standard technology. The main advantages of RCC pavements include [1, 9, 10]:

- high durability, especially with regard to rutting resistance and load-bearing capacity,
- light-coloured pavement: lower maintenance costs (60% less electricity for lighting), greater safety: solar reflection in summer, better visibility after dark and lower surface temperature than asphalt pavements,
- short construction time, quick putting the structure into operation, average speed for laying RCC is 60–120 m/h, light traffic loads are possible after just 24 hours,
- the possibility of using the equipment used for asphalt pavements, which significantly improves the availability of this technology also as a pavement of, for example, municipal or technical roads,
- transport using dump trucks instead of concrete mixers,
- elimination of passive water from the concrete resulting in less concrete shrinkage and reduced use of expansion joints,
- low construction cost; the cost of constructing 1m<sup>2</sup> of concrete road can be up to 20% lower than a road made with asphalt technology.

Few disadvantages of roller-compacted concrete (RCC) pavements include: problems in achieving pavement evenness.

#### 5. POSSIBILITIES OF USING ROLLER-COMPACTED CONCRETE FOR MUNICIPAL ROAD CONSTRUCTION

Local roads (municipal and district roads) account for 88% of the total length of the road network in Poland [10]. It is estimated that around 70% of roads under local government management are in poor and unsatisfactory condition, and according to the CSO, less than half of municipal roads have a paved – improved pavement. For this reason, the use of RCC technology for municipal road construction should be

considered as a solution that guarantees longer pavement life at a relatively low construction cost. The pavement made with RCC technology has a lifespan of at least 30 years, plus the maintenance costs of such a pavement are very low. This technology reduces costs by several percent compared to a bituminous road of the same category. The availability of the equipment used for the construction of municipal roads (asphalt pavers, rollers) also argues in favour of using this technology for the construction of municipal roads.



Fig. 2. Roller-compacted concrete pavement in the course of Inowłodzka street in Warsaw (photo by Adam Ćwiliński)



Fig. 3. Roller-compacted concrete pavement in the course of Jesiotrowa street in Warsaw (photo by Adam Ćwiliński)

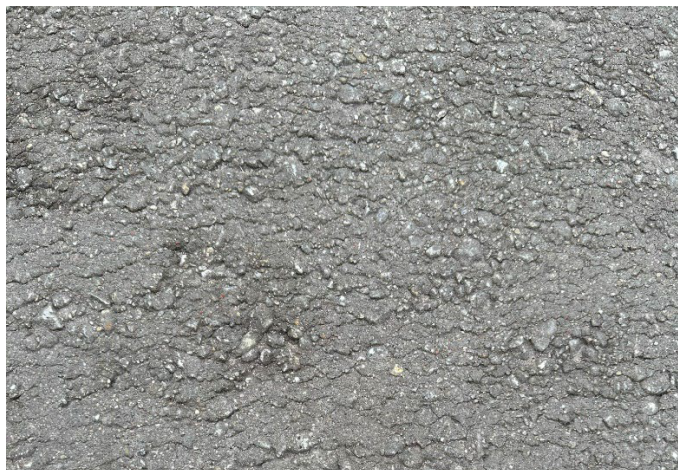


Fig. 4. Roller-compacted concrete pavement texture in the course of Inowłodzka street in Warsaw (photo by Adam Ćwiliński)

In 2018, several sections of streets with C30/37 class roller-compacted concrete pavement were constructed in Warsaw, including Inowłodzka, Jesiotrowa, Ruczaj, Platanowa, Makowska streets.

The pavement was made of concrete with the following composition [11]:

|                 |         |
|-----------------|---------|
| – cement        | 270 kg, |
| – sand 0/2 mm   | 920 kg, |
| – gravel 2/8 mm | 491 kg, |
| – water         | 95 kg.  |

The concrete taken during paving was further characterised by:

- a splitting tensile strength of 3.2 MPa,
- resistance to freezing/thawing with the use of deicing salt after 56 cycles.

The figures (Fig. 2, Fig. 3, Fig. 4) show the pavement of Warsaw streets made of RCC after 5 years of use. Based on observations after 5 years of operation, it can be concluded that the condition of these sections varies, which is indicative of the quality of their workmanship. Sections in good condition predominate, but there are sections where, in addition to the evenness problems, there are, for example, cavities, cracks, flaking and chipping on the joints.

## 6. ROLLER-COMPACTED CONCRETE WITH RECYCLED MATERIALS

Attempts are known to use recycled concrete aggregate [12], recycled asphalt pavement (RAP) [13, 14, 15], brick rubble [16] for the roller-compacted concrete.

The authors of the study [12] investigated the effect of using recycled coarse aggregate on the performance of RCC. Little can be found in the literature on the issue in question. Based on the results of 12 different mixes, it was concluded that it is possible to use 100% recycled coarse aggregate in RCC for use in the road pavement subbase.

Attempts to use RAP in RCC [13, 15] have shown that the properties of RCC decrease as the RAP content increases. The de Larrard model, which takes into account the quality of the adhesion of the aggregate to the cement matrix, has shown that the presence of RAP adversely affects this area.

On the other hand, the authors of the study [14] noted that when up to 20% RAP is used in RCC, there is no significant difference in terms of the concrete's resistance to freezing and thawing.

The authors of the study [16] used brick rubble as a substitute for sand. In addition, silica dust was used to improve the mechanical properties of the concrete. The results of the study showed that replacing up to 25% of the brick waste with sand did not result in any significant negative effects. The addition of silica dust has improved the properties of the concrete and is able to offset the negative effects of using brick waste in RCC at dosages above 25%.

The GDDKiA specification [2] allows the use of recycled mineral aggregates for the production of roller-compacted concrete. Materials from the demolition of the previous pavement (e.g. aggregate from recycled concrete slabs) can therefore be used to produce RCC.

## 7. SUMMARY

The use of roller-compacted concrete in the construction of local roads is a good option due to the availability of equipment, speed of construction and low construction costs, with a relatively high durability of the pavement. Problems with achieving pavement evenness are not an obstacle to the use of roller-compacted concrete for the pavement of lower class roads, such as local roads and industrial roads.

The problem of using waste materials in RCC has not received much attention to date, but the preliminary results of the research presented indicate that it could be a way to solve the problem of waste disposal and reduce the consumption of natural resources.

RCC with recycled aggregate could be an interesting solution for local road construction, but requires further research to optimise the concrete composition.

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