Development of thin layers (patches) made of waste tires for pavement foundation

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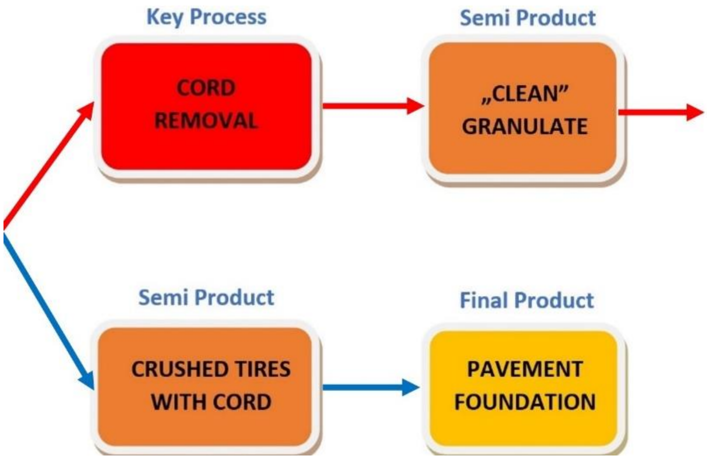
THE PROBLEM. The massive waste tires are occupying large areas and only part of them are recycled in the form of "clean" granulate after the costly metal cord removal. The diagram below shows the direct processing of the waste tires including the recycled material together with the cord.



INTRODUCTION. Currently the techniques for pavement foundation/ substructure face the following problems: (1) Use of commercial materials (i.e. cement, additives) generating waste during their production, (2) No or much limited water drainage for further its infiltration through the soil, (3) Unwanted process of cement hardening under the pavement, (4) Fragile to the vibration of surrounding infrastructure (tram tracks, road traffic etc.), (5) Long-lasting, loud and unaesthetic assembly, (6) Local subsurface collapse (Fig. 1).

THE SOLUTION.

The invention relates to both a **waste-tires based product** and a **method** of processing it by using waste car tires by means of cutting and grinding and chemical or thermal bonding into rubber patches (*PLASTRY Kuligowskiego®*) serving as underlays for paving slabs, etc. stabilizing the soil against local subsidence. The given above idea has the following additional advantages:

CIRCULAR ECONOMY: Utilization of raw tire waste from the very early stage of their value chain: in the form of scraps and shavings, together with metal cord, that is normally costly removed for further processing of the granules to smooth rubber layers for playgrounds and urban surfaces.

ADAPTATION TO CLIMATE CHANGE: Providing drainage of rainwater from concreted cities (currently only 15% of water flows away) through a system of channels. The PLASTER itself is highly permeable so probably it would not need any further drilling and perforation to allow water infiltrating through.

PREVENTION OF CEMENT CONSUMPTION: Elimination of cement-sand bedding under paved surfaces.

Fig. 1. Visual effect of collapsing pavement structure due to unstable subsurface

Additionally the following effects could be noticed: (1) IMPROVING ACOUSTICS and ELIMINATION OF VIBRATIONS in buildings during operation, (2) EASY TO ASSEMBLE AND DISASSEMBLE: in case of emergency earthworks, (3) HIGH AESTHETICS OF THE PLASTER, (4) NOISE REDUCTION during the performance of the service, (5) NO COLLISION OF THE SURFACE as a result of washing out the ballast and damage caused by insects and small animals (e.g. ants, moles).

HYPOTHESIS. The idea is to replace the currently used cement-sand based technique with less (1) material usage and mostly important (2) waste materials usage! The baseline is the economics of the cement-sand bedding: (1) The cost of the currently practiced pavements foundation based on cement-sand bedding is ca. PLN 150/m^2 (1: 1 material: labour), (2) Weight of 3 cm thick patch with an area of 1 m^2, with a rubber density of 0.75 kg/L (on average 0.65-0.95) is 22.5 kg/m^2, (3) The price of the granulate itself, e.g. from the company BRIDGESTONE (Poznań) is 200 EUR/t (about 1 PLN/kg), so the cost of the material is 22.5 PLN/m^2, (4) The cost of producing a 3 cm patch (PLASTER) without holes is PLN 125/m^2. Finally (5) In order to be competitive with the current services, together with the raw material and energy cost of producing a patch, it should be below PLN 75/m^2. It is possible by using a raw material other than pure granules and by limiting the technological line.

The following thicknesses were used for testing: 5 and 6 cm. According to the requirements, the cement and sand bedding is usually 1: 4 (1 part of cement and 4 parts of sand and water to the optimum moisture content) should be 3 to 5 cm thick. Since our reference material has such thicknesses (and thus also the load capacities) and by way of comparison: what devastation 40 tons of load does if it is applied to 3, 4 and 5 cm of ballast, both distributed in half on adjacent elements (max. settlement) and only on one element (max. shear). Of course, it would be great and extra if it turned out that 5 cm of cement-sand backfill corresponds to 1 or 2 cm of the thickness of Kuligowski PLASTER®.

METHODOLOGY. The research method for cable sewer well covers was used: A15 covers can be installed in lawns, Covers B125 in sidewalks, C250 covers in gutters and shoulders, D400 covers in the road lane, E600 covers on airport runways. This is the only document that talks about permanent deformation and bearing capacity.

Mechanical test	Effect
1. Concrete paving blocks, Holland model, **6 cm** thick and 20x10 cm in size – plaster from the pulp 2. Concrete paving blocks, Holland model, **6 cm** thick and 20x10 cm in size – plaster from the granulate Load on B125 KN (12.5 tons)	End of test: result - components are broken. High subsidence. Patch assessment after examination - whole.
3. Concrete paving slab 40x40 cm **5 cm** thick - plaster from the pulp Load A15 KN (15 tons)	End of test: result - item complete. Low subsidence Patch assessment after examination - whole.

a. After the 5th cycle, there was a main cycle from 0 to **15 kN** at a rate of **1.0 kN** / second	
3. Concrete paving slab 40x40 cm **5 cm** thick - plaster from the pulp Load A15 KN (15 tons) b. After the 5th cycle, there was a main cycle from 0 to **30 kN** at a rate of **2.0 kN** / second	End of test: result - item complete. Moderate subsidence Patch assessment after examination - whole.
4. Fatigue test: Load A15 KN (15 tons) a. **50** preloads up to **15 kN** at a rate of **1.0 kN** / second	End of test: result - item complete. Low subsidence Patch assessment after examination - whole.
4. Fatigue test: Load A15 KN (15 tons) b. **5** preloads up to **35 kN** at a rate of **2.0 kN** / second	End of test: result - component broken. High subsidence Patch assessment after examination - whole.

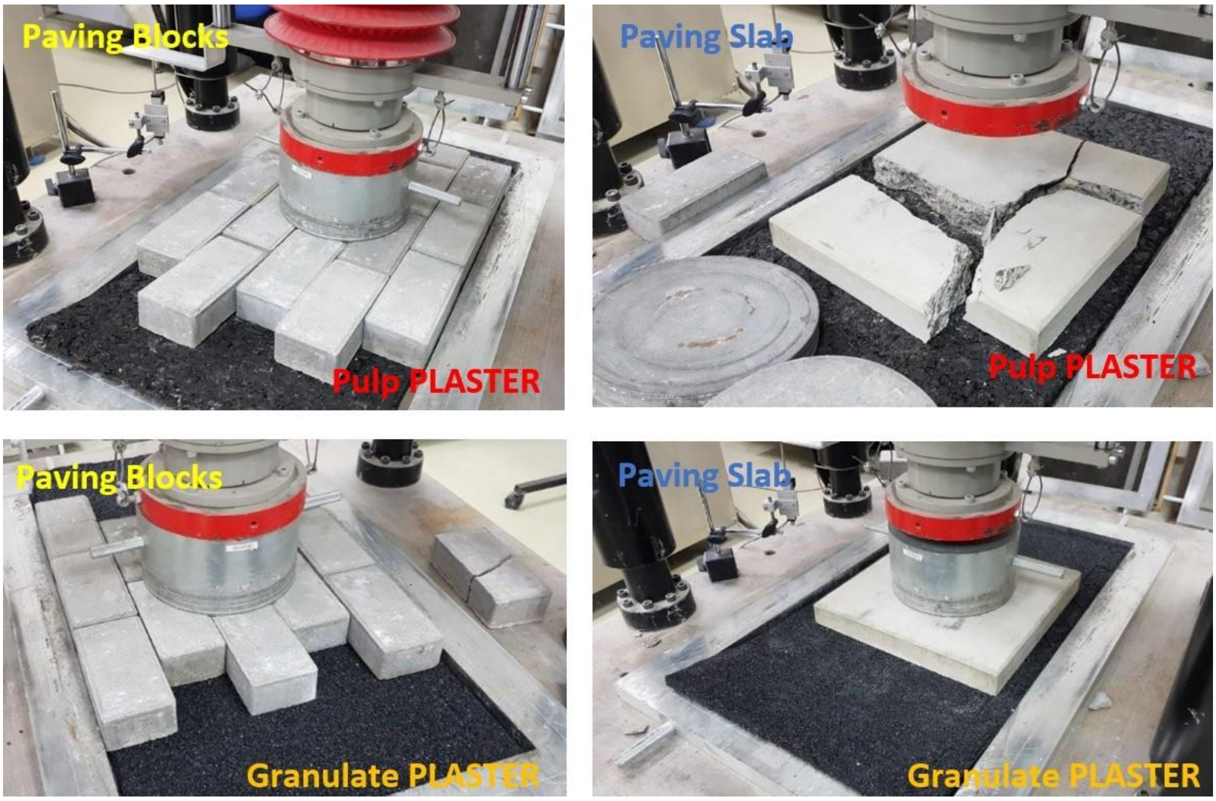


Fig. 2. Mechanical tests of pulp PLASTERs (up) and granulate PLASTERs (down) used as subsurface for concrete paving blocks (left) and for concrete paving slab (right)

RESULTS. The hypothesis was that the plasters could withstand the load class B125, but unfortunately the concrete elements 5-6 cm thick broke. The PLASTER slices withstand loads **up to 30 kN (3 tons)** centrally applied to the 40x40x5 cm paving slab, and then the deflection is so large that the tensile stresses in the concrete are exceeded and the concrete is destroyed with further settlement.

Fig. 3. Recycled “clean” granulate from preprocessed waste tires turned into products (left) and PLASTER Kuligowskiego® based on raw tire waste (right)

The general conclusions are:

- Low subsidence at 30 kN - 1.1 mm,
- Product application: only light pedestrian traffic - pedestrians and cars up to 2.5 tons at a speed of 20 km / hour. Delivery traffic not recommended,
- Pulp and granulate slices do not differ from each other in the transfer of loads A15.
- With the A30, there is already a much better plaster from the pulp, because the settling is less than 1.1 to 1.6 mm.
- Theoretically, PLASTER slices can be placed under a pavement made of paving slabs for pedestrian traffic.
- During the test, the issue of the tolerance of the height of prefabricated elements, thickness +/- 3.0 mm, was raised, which means that in extreme cases this difference may be 6 mm and this is an unevenness on which a person may trip and fall.
- The plaster from the pulp lets the water pass like a colander. The one from the granules is not.

The mechanical tests allowed to make the following conclusions: (1) People can walk on it, (2) Only light vehicles up to 2.5 tons occasional and occasional, (3) We know not to push this product into car traffic because the pavement can crack, (4) Paving stones with PLASTERs below resisted up to 5 tons, (5) Public sidewalks are intended to serve as “routes of life” for evacuation and to ensure the passage of emergency vehicles and the ability to pass is not the same as a damage-free ride.

Attention should be paid on all the variables resulting from the heterogeneity of the tire composition depending on the intended use (passenger / truck, summer / winter / all-year-round, completely worn (bald) / new or almost new), so that the lowest thickness plaster that will be stable, reliable and safe can transfer any possible permissible loads for a given surface (it must be remembered that each public surface must allow the entry and passage of 1 emergency vehicles, including a fire truck with a capacity of 115 kN / axle) 1 vehicle must enter and drive safely, but the sidewalk or road may be in such action damaged for later repair

Besides the idea-giver has developed the cooperation with the following parties to further implement the tested product: (1) National certification unit, (2) PLASTERs manufacturing technology partner – a company who already produces products based on rubber mixtures and safe surfaces made of rubber granules, which are used in playgrounds, sports fields, sport mats, (3) PLASTERs paving partner – a company who can build the first large-scale demonstration pavement, parking lot or square and (4) PLASTERs sales & construction partner – a classical roads and pavements company that could offer the PLASTER products together with their assembly and servicing. So the following stages are completed: 1. Basic mechanical research, 2. Patent application, and these ones are pending: 3. Certification, 4. Implementation, 5. Sales

The areas of further attention are:

- Water permeability in m3 / hour
- Load capacity according to the proposed test: plaster and over pavement surface after the test are to be undamaged,
- Permanent deformation not greater than… ..% or… ..mm
- Positive result of the test of leachability of hazardous substances (obligatory for products or construction products obtained from waste materials).
- Positive result of the radioactivity test,
- Possibly flammability test and reaction to fire for class A1 (700-800°C within a specified period of several minutes).
- Large-scale tests of 100-1000 m^2 paved surface,

This proposal is in line with the objectives of the **Circular Economy Action Plan**, which focuses on the sectors using a high amount of resources, where the potential for improvement is high, like plastics, textiles, construction and buildings. The proposal is also coherent with the **EU Green Deal**, namely it supports reduction of net greenhouse gasses emissions by 2050 and helps decoupling the economic growth from resource use by recycling waste tires into products in urban paved areas. This action is in line with the **Waste Framework Directive**. The Directive also requires that waste will be managed without endangering human health or harming the environment, without risk to water, air, soil, plants or animals. The Directive criteria also specify when certain wastes cease to be waste and become a product, or a secondary raw material.

READINESS. The Technology Readiness Level (TRL) of this technology is around still rather low meaning ca. 4-5; the mechanical tests are finished, but the following activities need to planned further:

Still some **technical problems** are to be solved, eg. regarding the PLASTER's water permeability:

Good - the greater the number of finer pores in the mass of the patch, the greater its strength, load-bearing capacity and lower deformability. From the point of view of strength and fatigue parameters, it is very good.

ISWM Framework Positioning of the Case Story

Stakeholders: Citizens, Local Authorities

Waste System Elements: Waste treatment, Recycling, Reuse

Aspects: Technical, Environmental, Financial, Socio-cultural, Institutional, Policy/legal

Not Good - for the ease of clogging and the loss of the permeable effect (seepage of water). And, the finer the pores, the easier it is to clog them with impurities (mainly silty-clay fractions) and cleaning the patches for economic and customary reasons is not an option (because the surface must be disassembled).

Good - the fact that the pre-prototype patches have sharp protruding pieces of reinforcement and the post-shear carcass is very good for the pavement stability. Of course, with sharp wires, they can be arranged downwards to the foundation, because concrete slabs must be placed on the even side of the slices. Proper protective clothing and information about the hazard and warning should do the job when producing the PLASTERs.

Not Good – we do not know how much the production costs associated with levelling the unevenness resulting from the heterogeneity of the PLASTER slices will increase compared to the cement and sand bedding, which does not cause these irregularities.

The technology is closely related to the Integrated Solid Waste Management (ISWM) framework. As the intended use in construction of urban paved areas, national and local authorities are responsible for decision-making and citizens (pedestrians and some drivers) are the final users. The covered Waste System Elements are: **tire waste treatment** via crushing, pressing, forming and chemical bonding, then **recycling** as patches or slices (PLASTERs) for pavements subsurface. "Financial/ Economic" benefits are expected due to savings in avoiding costly cord removal technological step prior to currently produced "clean" granulate and also due to avoidance of "rainwater tax" for the property owner, due to better water permeability of the paved area after application of PLASTERs. There is a number of mentioned earlier environmental benefits as well, i.e. water permeability, waste tires recycling, prevention of cement production, reduced noise nuisance at construction stage, low or no subsidence nor collapsing of the paved areas, whereas "Sociocultural", "Institutional", "Policy/ legal/ political" factors need to be considered if scaled out and applied in real scale.

Lessons learned:

- Waste tires "wild" dumpsites are often a massive problem that is not well managed yet,
- Waste tires could possibly ne turned into a new product omitting the costly cord removal step,
- The technologies for forming the new PLASTER products is available and does not need any serious adjustments,
- The manufacturer of such waste tires - based patches should either obtain an environmental permit to process the waste tires into "dirty" granulate and then to PLASTERs or obtain the "dirty" granulate from other body that has such a permit to convert waste into semi-product,
- Some technical problems need to be met such as material uniformity, water permeability, mechanical and safety aspects,
- The final price has to be estimated to better address the competitiveness to classical cement-sand bedding,