EFFECTIVENESS OF GLASS FIBER MESH REINFORCEMENT APPLIED TO ROAD CONSTRUCTION LOCATED IN A MINING SUBSIDENCE AREA

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Abstract. *Local district roads represent low technological regime when it comes to rehabilitation treatments. Analysed road is located in a mining subsidence area in Upper Silesia in Poland. Glass fibre mesh interlayer reinforcement had been tested numerous times at different roads. The main objective of this paper is to investigate the effectiveness of applied reinforcement for road located in a mining subsidence area. Evaluation was performed by determining a state of cracking indicator in accordance with visual-method of pavement surface evaluation. Results shows high effectiveness of applied reinforcement. Further researches are recommended.*

Keywords

Interlayer reinforcement, glass fibre mesh, mining subsidence, pavement distress.

1. Introduction

Local district roads represent almost 30% of all roads managed by local government units next to national, voivodeship and municipal roads. From road administrator point of view efficient management of a road network affects the attractiveness of adjacent areas in both investment and living desirability. Because of that local roads are significant point in budget plans of local government units. In the last few years we can observe a trend to apply an interlayer reinforcement in pavement construction, e.g. glass-fiber mesh with or without additional fabric.

Glass-fiber mesh is a bidirectional reinforcement embedded in-between pavement's asphalt layers. Proper application allows right cooperation between asphalt concrete layers and by that provides optimal transfer of interlayer stresses, associated with load, from layers to reinforcement [5]. Mesh reinforcing of flexible pavements achieves one or more objectives [8]:

- Prevents reflective cracking.
- Improves the fatigue resistance of asphalt concrete layer.
- Improves shear resistance against rutting in high stress locations.
- Improves bearing capacity.

Objectives showed above indicate great contribution of reinforcement to the lifetime of the pavement, which also decrease the road maintenance costs over time. Many roads in analysed district are located in mining subsidence areas. Reinforcing a pavement construction previously deformed by mining subsidence may prove ineffective according to short time-periods between rehabilitation treatments [3]. In the mining subsidence areas proper selection of pavement construction is crucial for its durability. Horizontal unloosing deformations ε_r influencing subgrade causes additional tensile stress ε_{xd} in pavement construction. Rigid pavements because of its high elastic modulus are prone to permanent deformations and damages. That is why in mining subsidence areas flexible pavements should be dominating, cost effective solution. In the mining subsidence areas due to the horizontal unloosing deformations ε_r, subgrade's bearing capacity lowers [3], [4], [7].

Additionally changes in state of stress in subgrade lead to ultimate bearing capacity, which further may cause excessive deformation. Because ultimate bearing capacity of construction is connected with subgrade ultimate bearing capacity, it decreases accordingly.

Additional factor that decreases the bearing capacity of the pavement construction is changing and unstable level of ground water, which often accompanies the mining exploitation. Major problem is that horizontal unloosing deformations cause tensile stress in construction and in-between construction layers – subgrade/subbase. This extra tensile stress may also cause the loss of integrity of aggregate base course. Additional tensile stress in upper layers of pavement construction, especially when temperature is low, may lead to intense propagation of cracking and asphalt concrete deformations. Cracking and road surface deformations are caused by additional dynamic load from road traffic. Clearly, the influence of mining subsidence is very dangerous for durability and safety of pavement construction. This leads to a problem of finding proper solution of protecting the pavement construction from mining subsidence, which applies to both new and rehabilitated roads.

Analysed section of pavement was rehabilitated in 2008 by milling existing asphalt layers and applying new ones – 3 cm of leveling course AC11P 50/70, 6 cm of binder course AC16W 50/70 and 4 cm of surface course AC11S 50/70. Right lane was additionally reinforced with fiber-glass mesh (tensile strenght 50/50 kN/m by elongation 3%) applied on existing construction under binder course while left lane was left without reinforcement. Analysed road is a district road managed by regional government unit, with service level KR4 (Polish classification), two-lane (2 x 3,0 m), two-way road with soft shoulders. Water is drained from the roadway by proper cross slopes into road ditches. Unfortunately there are no current load traffic data – based on road service level load traffic should be between 336 – 1000 equivalent single axle loads of 100 kN per day per traffic lane. It lies in the mining subsidence area of 2nd category (terrain elevation 2,5 mm/m < T < 5,0 mm/m, curvature radius 20 km > $|R|$ >12 km, horizontal ground deformation 1,5 mm/m < $|\varepsilon|$ < 3,0 mm/m) in Upper Silesia. After 10 years it was decided to analyse the effectiveness of applied solutions, having in mind continuous mining subsidence influence. It is worth considering whether the fiber glass reinforcement prolonged the lifetime of the pavement or not.

Advantages of using interlayer reinforcement mentioned before are widely described and examined, however the technological regime for work performed on local roads is lower and far away from recommended by technological standards. Effectiveness of geocomposite was proven in many practical applications [1], [2], [6]. A lot of communication infrastructure is working correctly in difficult ground conditions due to proper application of geocomposite [1], [6], [8], [9], [11]. However, failures of pavement surface after short time of usage still happens despite applying reinforcements [1]. It is a result of improper choose of reinforcing material on design stage and later mistakes during execution of work. According to [1] amongst the most often errors considering technology regime and technical standards for geocomposite are:

- Misinterpretation of tensile strength with long time durability.
- Not enough knowledge about geosynthetic materials rheology.
- Assuming that multiple layers of geosynthetic in one constructions sum their durability to tensile strength.
- Assuming too high allowed elongation (even 20%).
- Changing geogrids to geotextiles by contractors.
- Using materials other than specified by documentation.
- Using pins in areas where geosynthetic should work freely.

2. Materials and Research Methods

State of cracking analyse was performed in accordance with a non-destructive visual method. It was created by General Directorate for National Roads and Highways – System for evaluation of pavement surface [14], [15]. Because of its reliability and simply rules of evaluating the pavement surface conditions it was used for purposes of this analysis.

System for evaluation of pavement surface includes following types of data [14]:

- Bearing capacity
- State of cracking
- Roughness index for longitudinal profile
- Rutting
- Frictional properties
- State of pavement surface

In this analysis main focus was to determine state of cracking, a parameter that describes loss of integrity of pavement surface. State of cracking is described by reliable indicator of surface cracking n_m based on visual inventory of following pavement surface distresses:

- Fatigue cracking.
- Longitudinal cracking.
- Transverse cracking.
- Potholes.
- Patching.
- Polished aggregate and ravelling.

The first step was to divide analysed road into four sections each 100 m long for each lane (reinforced and unreinforced) and inventory the surface distresses. Next step was to categorize them by degree of severity into two groups, low severity cracking (sealed and not wide-

Tab. 2: Classes of pavement surface condition [15][16]

Class of condition	A	B	C	D
n_m indicator values	$n_m > 0{,}90$	$0{,}90 \geq n_m \geq 0{,}56$	$0{,}55 \geq n_m \geq 0{,}41$	$0{,}40 \geq n_m$
A – good condition	New and rehabilitated surface that does not require treatment			
B – sufficient condition				
C – insufficient condition	Surfaces with distresses that require planned treatment			
D – bad condition	Surfaces with distresses that require immediate actions			

open or unsealed but without crumbled edges) and high severity cracking (unsealed and wide cracks with crumbled and cracked edges). Inventoried and categorized distresses mentioned above were then used to determine a reliable indicator of surface cracking n_m for 400 m section of road divided into four 100 m sections for each lane, in accordance with formulas included in Appendix A to system for evaluation of pavement surface [14]. Pavement surface evaluation was performed by using n_m indicator to assign proper class of condition with table 1 [15].

Fig. 1: Examples of analysed road's distresses, longitudinal and fatigue cracking.

Methodology used for preparing an inventory differs from the original one in reference to longitudinal cracking in an axis of the section, between two lanes. It was not assigned neither to left nor right lane because the main objective was to determine the effectiveness of used rehabilitation treatments.

Therefore assigning this particular longitudinal cracking to one of the lanes would disrupt the results. Those longitudinal cracking in the road axis are between 15 – 45 m long and appears in every 100 m section.

Except defining the state of cracking factors, collected data were analysed for range and quantity of distresses in each section of every lane. Main purpose was to determine the influence of interlayer reinforcement on frequency of distress occurrence. Distresses were inventoried by [14] methodology and compared directly without determining the n-factors. Because state of cracking is used for planning the necessary rehabilitation treatments, additionally it was compared to indices of cracking determined accordingly to [13]. It is simplified method of categorizing the pavement surface condition by intensity of transverse cracking and is determined only by this type of distress. Together with [14], [15], it is used to decide the most appropriate treatment method.

$$I_s = \frac{1}{2} L_n + L_p \qquad (1)$$

where:

I_s – index of cracking

L_n – amount of transverse cracks per 100 m (narrower than width of a lane/road)

L_p – amount of transverse cracks per 100 m (full width of a lane/road)

Sections are then divided into three groups:

$I_s < 0{,}5$ – non-cracked sections

$1 < I_s < 3$ – medium cracked sections

$I_s > 3$ – heavy cracked sections [13]

State of cracking indicator n_m allows to predict the loss of bearing capacity which then has to be confirmed by deflection measures. The index of cracking I_s pictures the intensity of cracking and thus informs us about rehabilitation treatment range as it can be performed to whole analysed surface as well as to single cracking. Also, the state of cracking indicator includes all mentioned distresses [15] while index of cracking includes only transverse cracks [13].

3. Results

After analysing the reliable state of cracking indicators showed in figure 2 we can notice that a road lane reinforced with glass-fiber mesh is classified into B-category – sufficient condition on each section of the lane. The unreinforced lane also qualifies into B-category with exception of second section that currently classifies for C-category. Values of the indicators differs by average of 0,14 and it is worth to mention that state of cracking indicators may be used to estimate the loss of bearing capacity (however it has to be verified with index of bearing capacity determined by deflection measure).

It can be presumed that unreinforced lane will require rehabilitation treatments much earlier than the reinforced lane, as its degradation will proceed faster over time.

Lower indicator value results in higher amount of distresses. Every additional discontinuity in asphalt concrete surface leads to proneness to chemical and physical factors such as water penetration, freezing damages, gas, oil and salt penetration etc.

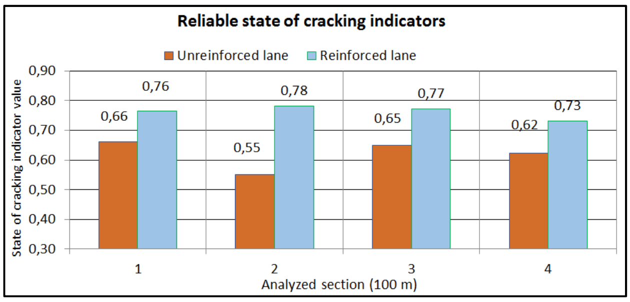

Fig. 2: Comparison of reliable cracking indicators.

During inventory no other distresses than longitudinal, transverse and fatigue cracking were spotted. Methodology of determining the reliable state of cracking indicators demands considering both transverse and longitudinal cracking as linear distress and thus calculating their influence together [15]. In the analysed sections it is worth to look at range and quantity of distresses in each section of every lane. Figures 3-6 show longitudinal, transverse and fatigue cracking divided by severity [15], lanes and sections.

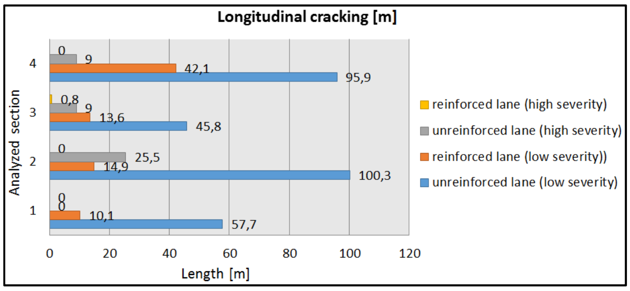

Fig. 3: Comparison of combined longitudinal cracking lengths.

Figure 3 shows summary length of longitudinal cracking. As we can see the quantity of cracks is noticeably higher in sections without glass-fibre reinforcement. In the lane reinforced with geosyntetic only one longitudinal crack with high severity was observed. On the contrary, we may notice that the largest quantity of distresses appears in the section 2 of unreinforced lane. It is the only section with condition class C- insufficient condition.

Figure 4 shows summary length of transverse cracking. Similarly to longitudinal cracking we can see that the quantity of cracks is noticeably higher in the unreinforced lane than it is in the lane reinforced with glass-fibre mesh. Analogical section 2 of unreinforced lane is the most distressed one and the quantity of cracks is two times higher than in section 4, which is second most damaged from all analysed sections. Again the lane reinforced with glass-fibre mesh shows almost no high severity distresses.

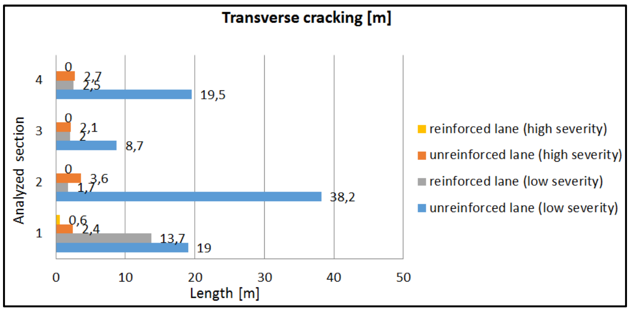

Fig. 4: Comparison of combined transverse cracking lengths.

Figure 5 represents the length ratios of longitudinal and transverse cracks between unreinforced and reinforced lanes, divided into four 100 m sections. Clearly in the lane reinforced with geosynthetic frequency of distresses occurrence is significantly lower than in the unreinforced lane. Again, section 2 shows the greatest difference between lanes as there are almost 23 times more transverse cracks and 7 times more longitudinal cracks in the unreinforced lane than in reinforced one.

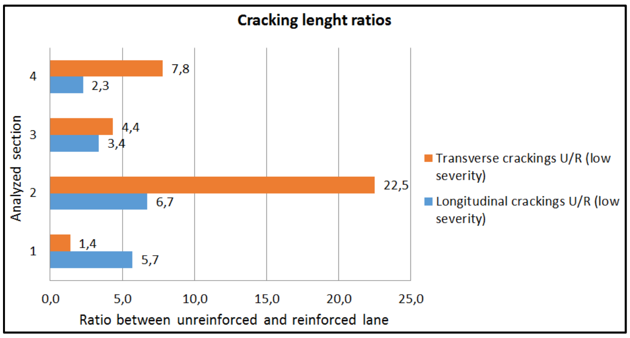

Fig. 5: Comparison of transverse and longitudinal cracking length ratios.

The lowest difference between lanes appears in section 3 of analysed road, which is the only section that is separated from the shoulders with concrete curbs. High severity transverse cracks are mostly wide on the whole lane width, however, they end at the border between unreinforced and reinforced lane and do not propagate into reinforced lane surface.

Figure 6 represents a comparison of fatigue cracking surface areas. In the analysed road no high severity fatigue cracks were observed. In reinforced lane we may observe smaller quantity of fatigue cracks except from section 2. Considering all previously presented figures, section 2 is the most interesting to analyse. Despite the unreinforced lane being significantly damaged (condition class C) the reinforced lane (condition class B) shows almost three times more fatigue cracks than unreinforced one. In any analysed section no potholes, patching or polished aggregate were observed.

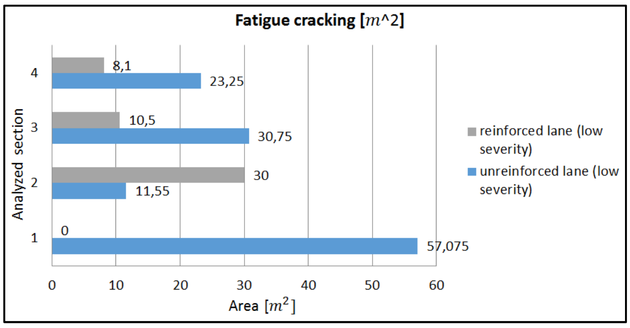

Fig. 6: Comparison of fatigue cracking surface areas.

Table 2 shows the comparison of reliable cracking indicators [15] with cracking indices determined by [13]. As stated previously every section with I_s index higher or even to 1 is considered medium cracked and every section with I_s index higher than 3 is heavily cracked and demands immediate treatment.

Tab. 2: Comparison of reliable cracking indicators with cracking indices

Section		1	2	3	4
Unreinforced lane	I_s	8,5	34	5,5	11
	n_m	0,66	0,56	0,65	0,62
Reinforced lane	I_s	4,5	1	1	1
	n_m	0,76	0,78	0,77	0,73

All sections of unreinforced lane and section 1 of reinforced lane are considered heavily cracked – the intensity of cracking requires rehabilitation treatments on whole surface, not only the cracking itself. The residual sections are considered medium cracked and treatment may only target cracking without necessity of repairing whole surface. This shows the difference between state of cracking indicator n_m reported earlier that allows us to predict the loss of bearing capacity and index of cracking I_s which pictures the intensity of cracking.

State of cracking indicator n_m allows to evaluate surface condition and serviceability time while index of cracking I_s determines whether rehabilitation treatment should be applied to single cracking or to whole surface. Even when bearing capacity is still acceptable, eventual treatment should be applied to whole pavement surface in this particular case.

4. Conclusions

Each of the analysed section is under different influence, which differentiate produced distresses, such as uneven embankment subsidence, water penetration inside subgrade and road construction, lack of hard shoulder or concrete curbs and mining subsidence. Reliable state of cracking indicators are approximately 15% higher for lane reinforced with glass-fiber mesh, which is also confirmed by intensity of cracking represented by indices of cracking. Analysed sections differs between themselves and section 3 is a good example. In this section pavement surface is bordered by concrete curbs with shoulders in good condition and it produces significantly lowest differences between reinforced and unreinforced lane. Clearly glass-fiber mesh improves the condition of the pavement surface, which is pictured by state of cracking indicators, state of cracking indices and by direct quantity of distresses. However overall road condition would greatly improve after bordering road with concrete curbs and providing right water drainage. Fatigue cracks amount in reinforced lane of section 2 may suggest that mistakes were made during application of mesh resulting in decrease of fatigue crack resistance. Rebuilding a whole road construction and embankment will be necessary in close future. After that it would be possible to analyse the impact of mining subsidence on surface pavement, now the group of factors is too wide.

As for costs it is definitely an efficient solution. Building in glass fiber mesh for a 100 m section of 6 m wide road is a cost efficient solution comparing to overall costs. It is worth noticing that in many cases rehabilitation treatment is used when in fact the road should be rebuild with full pavement construction and following infrastructure, considering the valid traffic load and ground water conditions.

Analysed road was rebuilt around 40 years ago. The exact subbase is hard to identify due to widening the road during last 40 years, which produces differences in stiffness among different areas of the road surface. That leads to problems with designing appropriate solutions for rehabilitation treatments. It must be pointed out that for optimization of proper solution, it is crucial to use the pavement structural design method that includes additional mining subsidence influence. Researches led before [3] showed that horizontal deformations have a major impact on pavement construction work, leading to change of subgrade bearing capacity in time and producing relative disparity in displacement between points in surface and subgrade which activates the horizontal friction on border between layers and causes additional tensile stress. Considering mining subsidence additional designing criteria were proposed [3]:

- Criterion of ultimate vertical stress in subbase (protects pavement surface from excessive permanent deformations caused in periods of changing bearing capacity of subgrade during to mining subsidence) .
- Criterion of ultimate horizontal stress in lower layer of subbase on the border with subgrade (protects subbase from losing bearing capacity).

Presented criteria will help to provide right solution for flexible pavement construction on mining subsidence areas, which should not be designed using the typical catalogues e.g. [13]. Analyses provided in this paper were performed on own measures. Data about existing pavement construction was gained from road management unit. Unfortunately geotechnical documentation was not prepared neither was a proper design of rehabilitation treatments applied in 2008. After this analysis, it is clear that using reinforcement in this particular road was a good solution, nevertheless, because of mining subsidence it should be monitored. For further researches geotechnical conditions, deflections and interlayer bonding will be determined. Then, it would be possible to continue the analyse and formulate wider conclusions including the glass fiber mesh efficiency during mining subsidence influence. Unfortunately the current group of factors influencing the analysed road does not allow to determine the mining subsidence impact and further researches are necessary to exclude other factors.

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