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Development of the road aggregate test specifications for the modified ethylene glycol durability index for basic crystalline materials

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Abstract: Many basic igneous rocks contain smectite clays as a result of deuteric alteration during their formation or subsequent chemical decomposition. This has resulted in numerous failures when such materials are used in road construction, due to inadequate durability. Various methods for assessing material durability have been developed and those using ethylene glycol (EG) to "expand" smectite clays appear to be the most effective. Protocols have been developed for a number of tests using EG but it can be difficult to quantify the results in terms of unique values and develop specification limits for use in road construction. A simple new protocol for an EG soaking test, the modified ethylene glycol durability index (mEGDI), has been developed and the proposed interpretation of results is compared with existing specifications in this paper. The mEGDI is suitable for use as a screening test to identify poor durability materials. However inconsistent correlations with existing specifications exist for materials classified as durable by the mEGDI test and such materials require traditional testing before acceptance. The development of a rapid mEGDI is being investigated to reduce the time required to complete the test and therefore provide a useful screening test methodology.

CE database Subject headings: Aggregate, durability, base course, pavements

Author keywords: Ethylene glycol, basic crystalline materials, durability, base

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Introduction

South Africa, like many countries with Mesozoic or later basic igneous intrusive rocks and lavas, has significant problems when many of these materials are used as construction materials. It is not uncommon for these materials to have undergone deuteric alteration during placement or to have erupted under marine conditions, resulting in the formation of smectite clays as a primary component of the rock. When such materials are used as construction aggregates, particularly in structural layers for roads, these smectite clays are released during processing, construction and in service leading to an increase in plasticity of the materials. This has the effect of weakening the road layer usually leading to premature failure (Fig. 1).

It has long been recognised that the presence of excessive smectite in basic crystalline materials can be identified by soaking the material in ethylene glycol. Ethylene glycol has the effect of being absorbed in the interlayers of smectite clays resulting in an increase in the interlayer spacing from 15Å to between 17 and 18Å. Over the years a number of test methods have been developed that make use of this property and allow an assessment of the quality of the material. These have been developed for tunnelling, railway ballast and aggregate, but experience has shown that it is very difficult to obtain a uniform single unique test result that can be used for the specification of road materials.

This paper describes the method originally presented by Paige-Green (2008) which is based on various attributes of existing methods and that can be used to quantify the action of ethylene glycol on a sample of crushed aggregate. A database of test results is then used to reconsider the initially proposed interpretation of the results. The test results are also compared with standard aggregate test results.

Existing test methods

The literature describes various methods in which ethylene glycol is used to predict the durability of basic igneous rocks. Firstly, some traditional testing methods are supplemented by testing material after soaking it in glycol for a set period of time. Sampson (1989) provides an example of this when soaking Aggregate Impact Value (AIV) (British Standards 1990a) test samples in glycol for 24 hours prior to testing. They found that the difference in AIV and glycol soaked AIV values was useful in identifying potentially poor durability.

Other tests specifically for durability testing using ethylene glycol have been developed. The most widely-used of such tests appears to be that developed by the US Army in about 1949 (Corps of Engineers 1969) in which a sample of about 5 kg of material between 19.0 and 76.1 mm is soaked in ethylene glycol for a period of 15 days. The material is inspected at least every 3 days and any changes noted. After 15 days, the material is screened through a 19 mm sieve and the percentage loss from the original dry sample is determined.

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Davidson (1972) described a modification of the Corps of Engineers test for road materials, using a different sized aggregate fraction (9.5 to 13.2 mm) and a 9.5 mm screen to determine the amount of break-down. This, however, did not give an adequately quantitative result to allow specification and rejection or acceptance (Fielding and Maccarrone 1982). Higgs (1976) also used a slightly modified version of the Corps of Engineers test to assess various “slaking basalts” from the west coast of the USA. He noted that the test should perhaps be extended to 30 days as a number of the samples showed additional deterioration between 15 and 30 days.

Fig. 1. Examples of premature failures due to excessive plasticity in base courses A: General surface failure, B: Rutting and aggregate loss in wheel tracks, C: Bleeding in wheel tracks, D: Bleeding in isolated areas, E: Bleeding and rutting being repaired by milling and replacement.

In South Africa, Orr (1979) investigated a number of Karoo dolerites of Jurassic age, which had shown signs of “rapid weathering” using the method described by Higgs (1976). Both Orr and Higgs gave only qualitative assessments of the deterioration. During construction of the Lesotho Highland Water Project in South Africa (OSC 1986) an ethylene glycol test to assess the durability of materials was developed using cylindrical specimens from drill cores. These cylinders are soaked in ethylene glycol and the degree of disintegration and time required to reach the worst condition are rated. An “ethylene glycol index” value is then calculated for each core. Similar work using slices of drill core and the degree and time classification described above obtained semi-quantitative ratings for each drill core tested (Van Rooy and Nixon 1990; Van Rooy and van Schalkwyk 1993; Haskins and Bell 1995; Bell and Jermy 2000).

Problems with existing methods

Two main problems with the existing ethylene glycol soaking test methods when applied to road aggregates are found. Firstly, where a number of randomly selected aggregate particles are tested, it is usual that only a small number of them show evidence of disintegration, while testing of a single cylinder (drill-core) is generally not representative of road aggregate. Secondly, a definitive single parameter for the durability is not attained, as there are three mutually non-exclusive values obtained: degree, mode of disintegration and time. A single value is necessary to allow the specification of the material in terms of the test result. The tests in which material is sieved after soaking can also give misleading results depending on the degree of breakdown that has occurred. Many aggregate pieces could split into smaller pieces or only lose some surface flakes due to spalling and therefore still be sound despite material being finer than the initial sieve size. The use of a smaller sieve size than that used to prepare the sample, as used in the Aggregate Impact Value (AIV) test, would be more indicative of significant degradation.

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Preliminary investigation of construction materials often starts with drilling of cores from the proposed quarry. Typically, the core is crushed and a test sample is obtained from this. This usually results in a relatively limited number of particles available for testing and generally insufficient material for standard tests such as 10 per cent Fines Aggregate Crushing value (10%FACT) (British Standards 1990b) or Durability Mill Index (DMI) (Sampson & Netterberg 1989). Experience has shown that, due to the variability that can exist in a quarry, it is usually better to test a number of samples from various points than to test a single or a few, pieces of drill core. The limited material available from cores makes it almost impossible to do this with existing glycol testing methods (and standard tests).

Because of these problems and the increasing need to evaluate potentially non-durable basic crystalline rocks, the following method has been developed and employed in a number of projects. The method allows multiple samples from drill core to be tested separately and can be utilized by site laboratories to perform quality control when mining sources of variable aggregate quality.

Proposed method

Based on a number of trials, the following test procedure has been found to be suitable:

40 pieces of more or less equi-dimensional aggregate about 13 to 19 mm in size are placed in a tray and covered by ethylene glycol complying with ASTM D2693. The aggregate pieces are placed in a fixed pattern (five rows of eight pieces) (Fig. 2) so that each particle can be individually assessed and its behaviour with time recorded. The material is inspected after 1, 5, 10 and 20 days and the number (and location in the tray) of each piece that has spalled, fractured or disintegrated are recorded at each assessment. The definitions of these three terms are as follows:

Spalled - shedding of small fragments from aggregate edges and surface

Fractured - splitting into two or three pieces

Disintegrated - splitting into more than 3 pieces

Fig. 3 contains examples of typical aggregate that have undergone each of these forms of disintegration.

Fig. 2. Example of a sample soaked in glycol in a regular pattern.

Fig. 3. Images of typical spalling (A), Split (B) and Disintegrated (C) aggregate.

A value of the Modified EG Durability Index (mEGDI) is calculated for each observation period by applying a weighting factor to the number of pieces affected by different forms of degradation and determining the sum of these weighted values. An example of a typical test result and the calculations used in determination of the mEGDI are shown in Fig. 4.

Fig. 4. Example of a result from a mEGDI test, including the calculations.

As the effect of the ethylene glycol depends on the accessibility of the liquid to the deleterious clays contained within the aggregate pieces (i.e. permeability of the aggregate to ethylene glycol), the test should be continued for 20 days to determine whether there could be a longer term durability problem. Should the material continue to deteriorate and the mEGDI after 20 days is greater than 1.5 times the mEGDI after 5 days, the material should be regarded as having suspect durability.

Interpretation of results

Paige-Green (2008) suggested the following tentative 5 day mEGDI criteria for different aggregate applications during the mEGDI test development:

Subbase – mEGDI < 20

Base course – mEGDI < 10

Surfacing – mEGDI < 3

Long term durability – Ratio of 20 day mEGDI to 5 day mEGDI < 1.5

Two subsets of data from a database of road aggregate test results were considered in this study, the first being all mEGDI results for materials that have known performance records as road aggregates and the second being a larger subset of mEGDI values for materials for which traditional aggregate testing results are available (but no performance information is available).

Initial interpretation of the results from performance-related database indicate that the 5 day mEGDI may not be a good enough indication of durability as some materials that performed poorly in service had indices of less than 10 (Fig. 5). These materials were, however, all quarry materials from quarries that either produced materials of variable durability (as identified by additional mEGDI and other tests) or produced poor 20/5 day mEGDI values. The importance of testing multiple samples from one quarry to identify variability and the importance of completing the 20 day test is therefore illustrated. Thus when multiple samples are tested and the 5 day mEGDI is used in conjunction with 20 day results a good correlation is seen with performance in service.

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Fig. 5. The performance of road aggregate vs. the 5 day mEGDI and the ratio of the 20 and 5 day mEGDI (all materials proving acceptable after more than 1 year are yet to show poor performance and in such cases the acceptable years in service is the age of pavement).

The results also show that some materials with acceptable performance in service had 20/5 day ratios above the proposed limit of 1.5 (Fig. 5). On closer inspection such high ratios were for samples that all had 20 day mEGDI values of 2.5 or lower and thus were not representative of poor durability but rather extremely low 5 day mEGDI values (maximum of 2.0). Such samples cannot be considered as having poor durability and as such the proposed criteria (Paige-Green 2008) need to be further developed as follows:

Long term durability – Ratio of 20 day mEGDI to 5 day mEGDI < 1.5 *if 20 day mEGDI>10.*

Considering this all samples with a 20 day mEGDI within the 5 day proposed limit (i.e. <10) were then set to have a 20/5 day ratio of <1.5. The adjusted results (Fig. 6) show a good relationship between the proposed limits and observed in service performance. One exception is the sample with poor performance but a ratio of only 1. This material is that identified in Fig. 5 as being from a quarry with two distinct materials, one poor and one sound. The poor material had a significant effect on the pavement performance and overshadowed the sound material performance.

Fig. 6. The performance of road aggregate vs. the 5 day mEGDI and the ratio of the 20 and 5 day mEGDI after correcting all ratios based on 20 day values.

Adjustments of the weightings proposed by Paige-Green (2008) could potentially improve correlations, however, since different materials have different amounts of spalling, splitting and disintegrating materials any adjustments to the weightings tend to result in inconsistent changes in the result patterns.

Current South African specifications (COLTO 1998) for crushed basic igneous rock used in pavement base layers dictate that the 10%FACT value should be at least 110kN and that the Aggregate Crushing Value (ACV) (British Standards 1990c) should be less than 29%. Based on the correlations presented by Sampson and Roux (1982) these limits are equivalent to a maximum Aggregate Impact Value (AIV) of 29.1 and 28.4% respectively. It is therefore assumed that an AIV of more than 29% is indicative of inferior material. Using the second database and comparing the AIV with the mEGDI (Fig. 7 and Fig. 8) it was seen that none of the samples obtained an AIV of more than 29 despite the wide range of mEGDI values reported. The AIV test, as well as the 10% FACT and ACV tests are, however, originally designed to test the durability of materials with respect to impact resistance and do not directly consider material degradation due to expansive clay minerals. The observed poor

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correlation is therefore predictable. However, after soaking the samples in ethylene glycol for 24 hours and performing the AIV test it can be seen that the material resistance to impact reduces significantly (increase in AIV) and many AIV values above 29 are obtained (Fig. 7 and Fig. 8).

Fig. 7. The 5 day mEGDI vs. the AIV and glycol soaked AIV.

Fig. 8. The 20 day mEGDI vs. the AIV and glycol soaked AIV.

The maximum allowable change in AIV after glycol treatment of 4% (as proposed by Sampson 1989) was consistently exceeded by all materials with a 5 day mEGDI of above about 7.5 (and 20 day mEGDI of 20). There is, however, no consistent trend in the change in AIV due to glycol soaking and for low mEGDI values a wide spread of AIV changes was observed (Fig. 9). High mEGDI values (>10) therefore seem to indicate, as proposed by the original method, a potential for a material to contain, and be weakened by, expansive minerals. However, not all low mEGDI values seem to indicate that a material will not be weakened by expansive minerals.

Fig. 9. 5 and 20 day mEGDI values vs. the change in AIV values due to soaking in glycol.

Fig. 10 shows the same 5 day mEGDI data as Fig. 9 after being converted from AIV to 10% FACT using the correlations presented by Sampson and Roux (1982). Also shown is the ratio of the glycol 10% FACT values to those of the standard test. The South African National Roads Agency Limited (SANRAL) has proposed a minimum value of 70% for this ratio. All materials with a mEGDI (5 days) of more than 10 had ratios below the 70% minimum or did not exceed 70% by more than 3 %. The materials with a mEGDI of less than 10 did not, however, consistently produce the required ratio and as such the direct conversion of the 70% ratio specification to a mEGDI is also not valid.

Fig. 10. 5 day mEDGI values vs. the 10%FACT and ratio of glycol soaked to normal 10%FACT values.

The COLTO (1998) specification for DMI of 125 for natural gravel base materials has recently been adopted by SANRAL for all base course materials. A more conservative maximum limit of 90 is adopted by TRL (1993). With the exception of one potential outlier all materials with a mEGDI (5 days) of more than about 25 exceeded the TRL limit while, as seen with other correlations, lower mEGDI values (less than 25) did not result in a consistent trend (Fig. 11). 20 day mEGDI values were even less consistent when the same comparison was made.

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Fig. 11. 5 and 20 day mEDGI values vs. the DMI values.

DMI tests were also performed on material soaked in glycol for 5 days. The results show more consistent DMI ranges for a narrow range of mEGDI values (Fig. 12). All materials with mEGDI (5 days) values of more than 20 were above the TRL DMI limit of 90. There was no specific mEGDI value above which the DMI limit of 125 was consistently exceeded. These limits are, however, considered to be much too high for material soaked in glycol and therefore the fact that all materials that have a 5 day mEGDI of more than 10 have a glycol DMI in excess of 70 is considered significant. Low mEGDI values once again did not consistently correspond to low DMI or glycol DMI values.

Fig. 12. 5 and 20 day mEDGI values vs. the glycol soaked DMI values.

The relationships discussed above are all problematic because although very high mEGDI values tend to correlate with poor AIV dry/glycol ratios and DMI values, low mEGDI values do not seem to follow any trend.

The change in DMI values due to glycol soaking is potentially a useful indication of the potential of a material to break down due to excessive internal tensile stresses caused by expansion of smectite clay minerals. The change (as a percentage of the standard DMI value) is, however, once again inconsistent at low mEGDI values (Fig. 13 and Fig. 14). There is also no consistent trend in Plasticity Index (PI) change between glycol soaked and natural samples, as would be expected. The change in the percentage of material passing the 0.425mm sieve after glycol soaking does, however, correlate reasonably with the 5 day mEGDI (R^2 = 0.52) and slightly better with the 20 day mEGDI (R^2 = 0.57). These correlations were linear with the following equations:

$$\Delta p0.425 = 1.3mEGDI + 4.8 \quad 5\ day$$

$$\Delta p0.425 = 0.8mEGDI + 3.7\ (20\ day)$$

Where Δp0.425 is the percentage change in the percentage of material passing the 0.425mm sieve after glycol soaking.

Fig. 13. 5 day mEDGI values vs. the percentage change in PI, p0.425 and DMI due to glycol soaking.

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Fig. 14. 20 day mEDGI values vs. the percentage change in PI, p0.425 and DMI due to glycol soaking.

The final interpretation performed is a comparison of different material results considering the current South African specifications and the observed performance of the road. Table 1 reveals that material from roads that had good performance (i.e. no rapid failures) almost all passed all of the specifications. This is expected and the only exception is for the SANRAL proposed specification which is not used as an official specification yet.

Table 1. Percentages of tests passed by samples from good and poor performing roads.

The material from poor (rapid failure) roads did not show similar results. Firstly the current 10%FACT specification passed all such materials while the SANRAL proposed 10%FACT ratio specification only allowed 29% of these materials. Both DMI specifications also passed the majority of these materials. The proposed mEGDI specification allowed only 14% of the samples to pass and when the additional data from the 20 day mEGDI was considered only 7% of the samples from poor roads passed. These results therefore appear to justify the use of the mEDGI.

The above results are based on the assumption that all samples from roads with poor performance are of inadequate durability. This is, however, not true as some materials from such sites passed all the current specifications. When reclassifying each individual sample as either good, when all current specifications are passed, or poor, when any of the current specifications are failed, the results in Table 2 are obtained. Here the mEGDI rejects some of the materials that pass all other tests and again allow a low percentage of materials that fail at least one of the current specifications to pass. The results also indicate that the current COLTO (1993) 10% FACT specification is too lenient as all materials passed despite failing at least one of the other tests. Since samples were defined as “poor” based on the current specification test results further interpretation of the percentages of DMI and 10%FACT results in Table 2 are irrelevant.

Table 2. Percentages of tests passed by samples from good and poor performing materials.

Potential rapid mEGDI test

The potential for water to be used as an additional indication of poor durability in materials was shown when some materials tested by Fielding and Maccarrone (1982) showed no

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degradation on soaking in ethylene glycol but showed significant degradation when later soaked in water. Way and Shayan (1986) proposed two mechanisms in which the presence of water may result in the observed (further) degradation when materials are soaked in water after soaking in ethylene glycol or in diluted solutions of ethylene glycol. In diluted solutions, water present in clays in the early stages of testing causes ethylene glycol to be able to enter the clay layers by entering the layers first and causing their initial opening. This is probably partly the result of the lower viscosity of dilute EG and water than the pure EG and hence an increased permeability. The EG appears to open layers but only opens some layers by a small amount so no more glycol can enter. When soaking materials in water after soaking in ethylene glycol, additional water can enter as the water molecules can now fit into previously closely spaced layers causing minor additional swelling and further degradation. The last stage of this process is what occurs when samples are soaked in water after being soaked in pure ethylene glycol.

Preliminary testing has indicated that this process may be used to reduce the number of days required to perform the mEGDI by, for example, soaking the material in water after soaking in glycol for 5 days. Following this procedure would make the test more practical in laboratories where results are required rapidly. Additionally, long term durability problems that may not have been revealed by the original method may be exposed by this additional soaking.

Conclusions

Experience in South Africa has shown that existing ethylene glycol soaking test results are difficult to interpret for their use with road construction aggregates consisting of basic igneous rocks. A method has thus been developed to produce a unique result combining the effect of degree, type and time of degradation. This has been related to various specification limits for different uses of aggregates in roads.

An initial database has shown that a 5 day mEGDI value of a single sample may be misleading. The use of results from multiple samples in conjunction with the 20/5 day mEGDI ratio is, however, a good indication of durability. The 20/5 day mEGDI ratio is, however, irrelevant when the 20 day mEGDI is within the 5 day specification.

The originally proposed interpretation of base course materials with a 5 day mEGDI of more than 10 or a 20/5 day mEGDI of more than 1.5 as poor durability materials agrees with results from other tests. Materials with such properties should therefore not be used as base course aggregates. However, due to the inconsistent correlations observed between current specifications and 5 day mEGDI values of less than 10, materials with such properties should be additionally assessed based on the effects of glycol treatments on the AIV or 10% FACT results as prescribed by previous authors.

As expected the mEGDI does not correlate well with other tests that do not test the true durability after full saturation and expansion of clay minerals. There is, however, a relatively good correlation between higher mEGDI values and results of other tests that have utilized glycol to cause expansion and consequent weakening of the materials (e.g. change due to glycol soaking in AIV, glycol and normal 10%FACT ratios and percentage passing 0.425mm in DMI test).

The mEGDI test results have been shown to more consistently identify materials that will not meet the current South African aggregate specifications, or performance requirements than, any one other test. The mEGDI test therefore has the potential to be an effective screening test for durability, after which potentially suitable materials can undergo comprehensive advanced testing. This is especially true during initial material investigations when limited sample masses are available. Additionally the good correlation between poor road performance and inadequate mEGDI results makes the test attractive for use as a quality control test during material production to isolate materials that are likely to be problematic.

With the development of a more comprehensive database the correlations presented here should be reassessed. The use of water soaking after the ethylene glycol soaking to speed up the EGDI laboratory testing methodology is under further investigation.

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Figure Caption List

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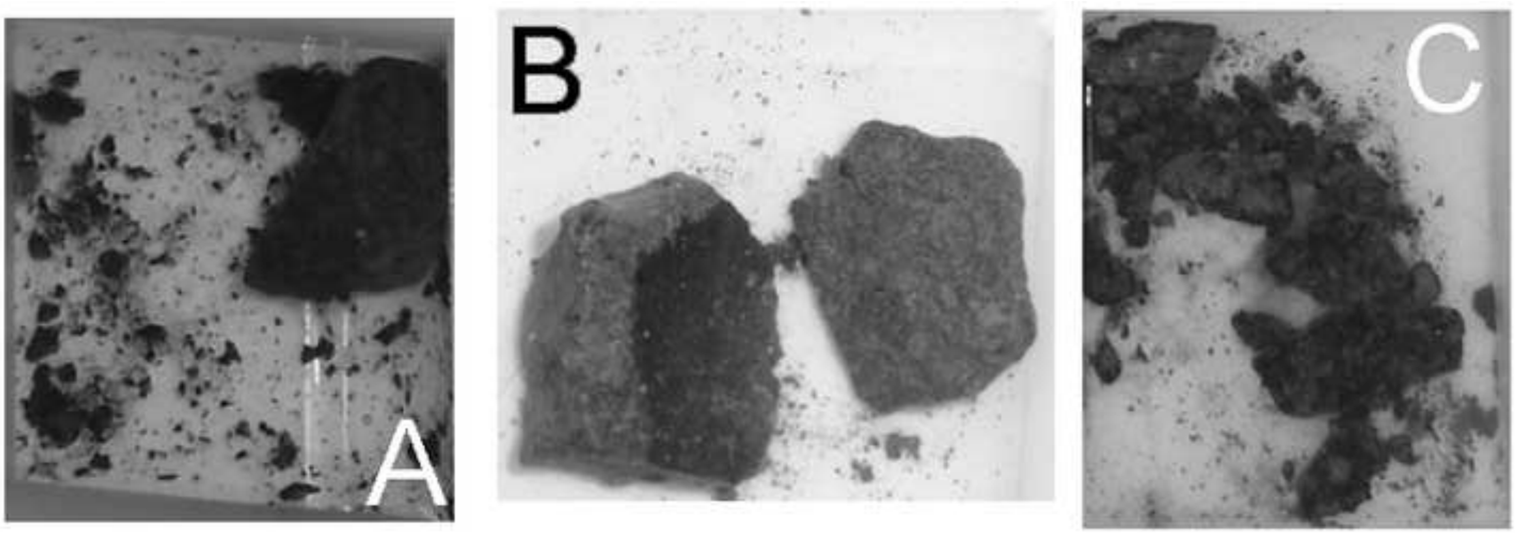

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Sample No.	Start Date	Technician
P3B1	15-Apr-12	LCR

1 day					Spall
5 days	Spall				Spall
10 days	Spall	Split			Spall
20 days	Spall	Split	Spall		Spall

1 day					Spall
5 days	Spall	Spall		Split	Disin
10 days	Spall	Spall		Disin	Disin
20 days	Split	Split	Spall	Disin	Disin

1 day					
5 days	Split		Split	Spall	Split
10 days	Split	Spall	Disin	Split	Disin
20 days	Split	Spall	Disin	Split	Disin

1 day				Split	
5 days			Split	Split	Spall
10 days		Spall	Disin	Split	Spall
20 days	Spall	Spall	Disin	Split	Split

1 day				Split	Spall
5 days	Split	Spall		Split	Split
10 days	Split	Spall		Split	Split
20 days	Split	Spall	Split	Split	Split

1 day	Spall	Spall		Spall	Spall
5 days	Spall	Split		Spall	Spall
10 days	Split	Split		Disin	Spall
20 days	Split	Split	Spall	Disin	Spall

1 day				Split	
5 days				Split	Split
10 days		Spall		Spall	Split
20 days	Spall	Spall	Split	Spall	Split

1 day		Split			
5 days		Disin		Spall	
10 days	Spall	Disin		Spall	
20 days	Spall	Disin		Spall	

Days	Number spalling (N_S)	Weighting (W_1)	Number spliting (N_{SP})	Weighting (W_2)	Number disintegrated (N_D)	Weighting (W_3)
1	7	0.5	4	1	0	2.5
5	11		12		2	
10	13		10		7	
20	15		15		7	

Calculations:

	$(N_S \times W_1) + (N_{SP} \times W_2) + (N_D \times W_3)$		mEGDI
1 Day	$(7 \times 0.5) + (4 \times 1) + (0 \times 2.5)$	=	7.5
5 days	$(11 \times 0.5) + (12 \times 1) + (2 \times 2.5)$	=	22.5
10 days	$(13 \times 0.5) + (10 \times 1) + (7 \times 2.5)$	=	34
20 days	$(15 \times 0.5) + (15 \times 1) + (7 \times 2.5)$	=	40

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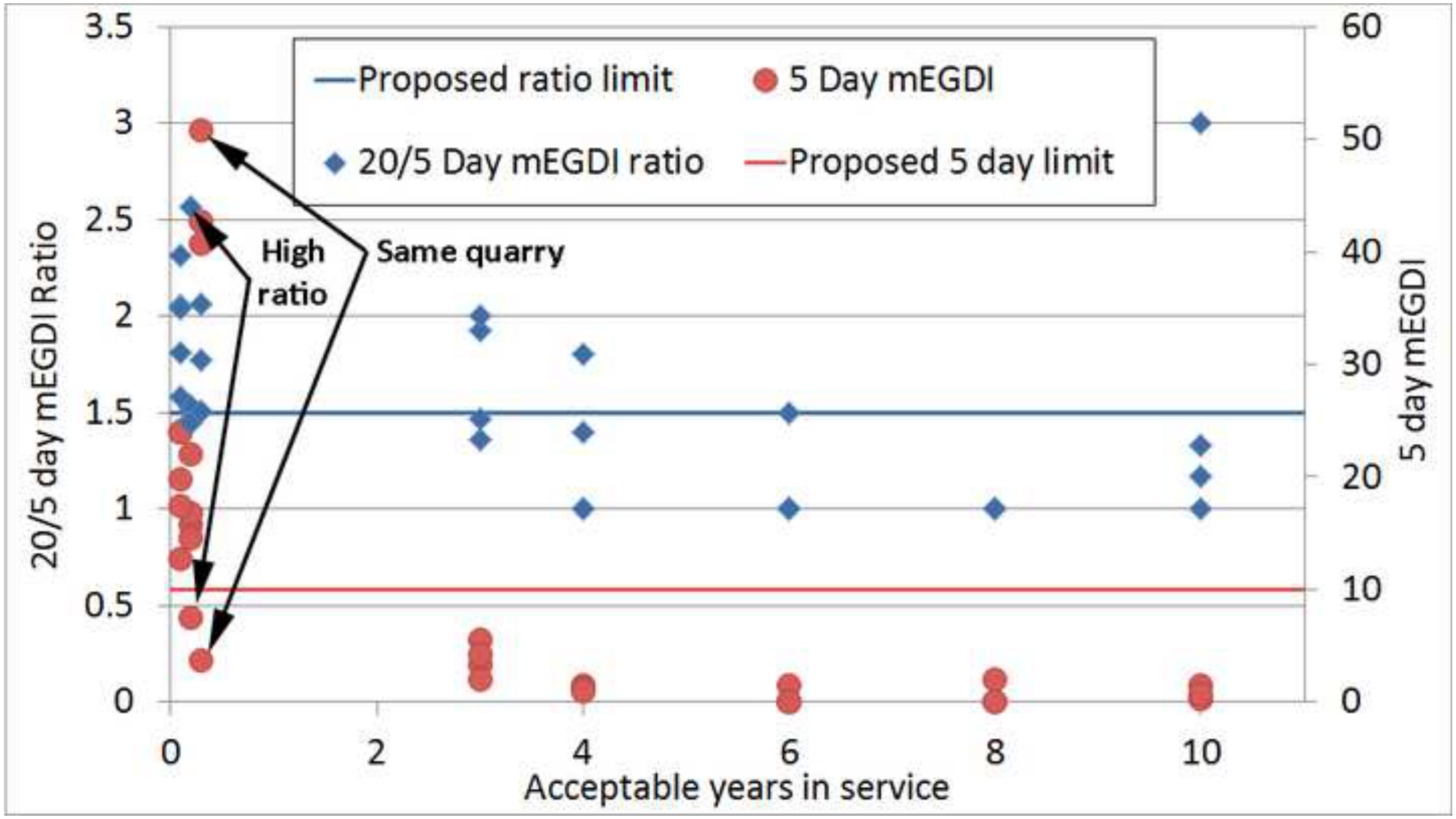

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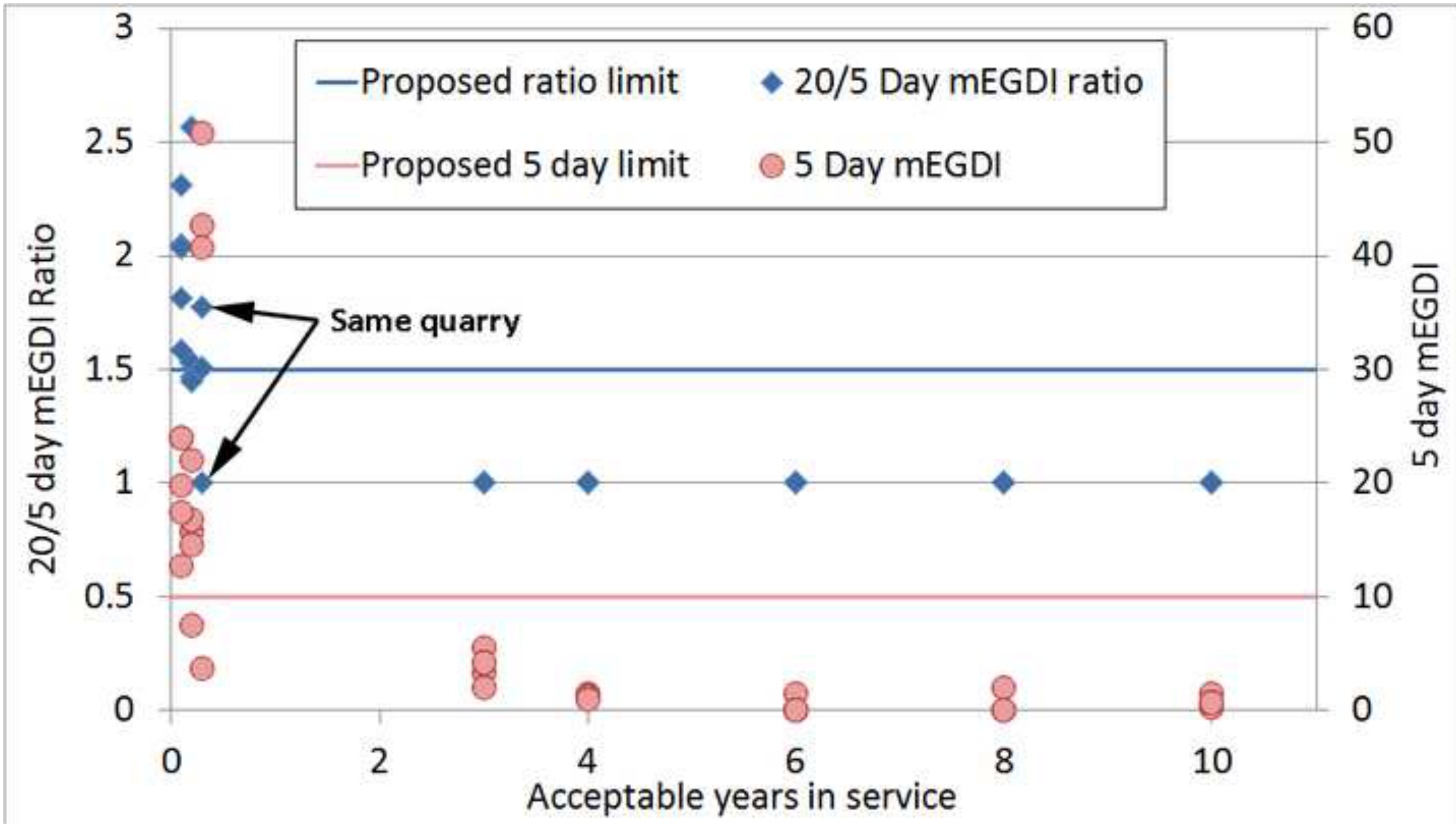

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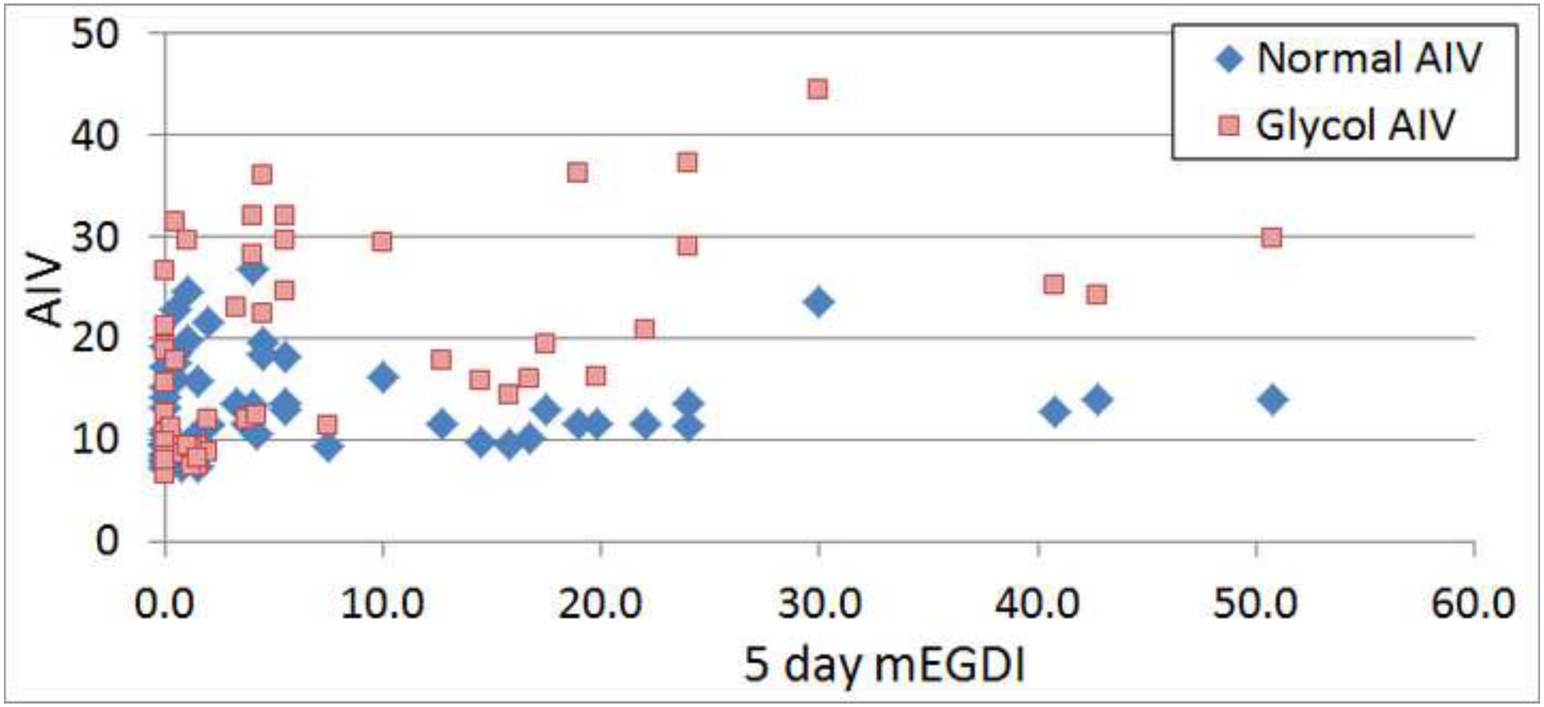

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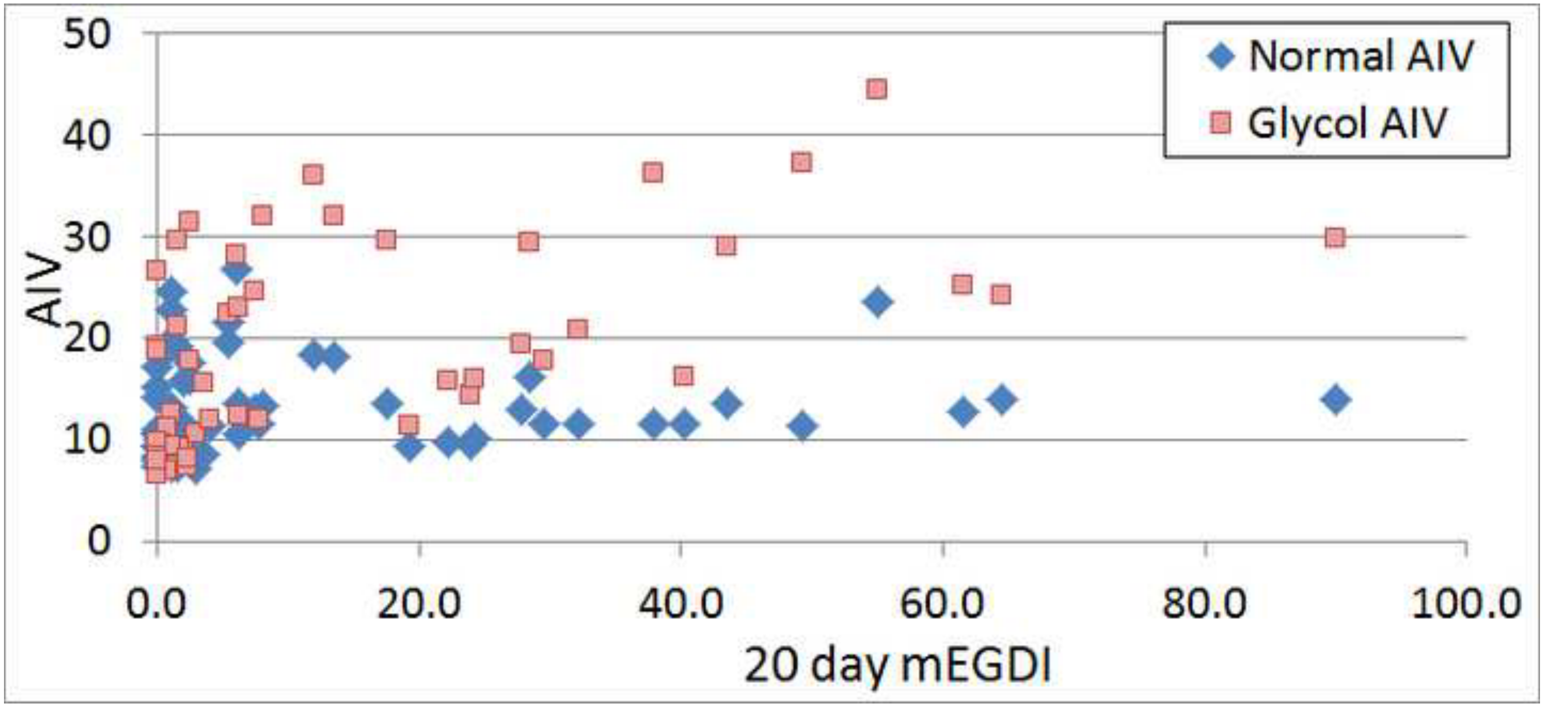

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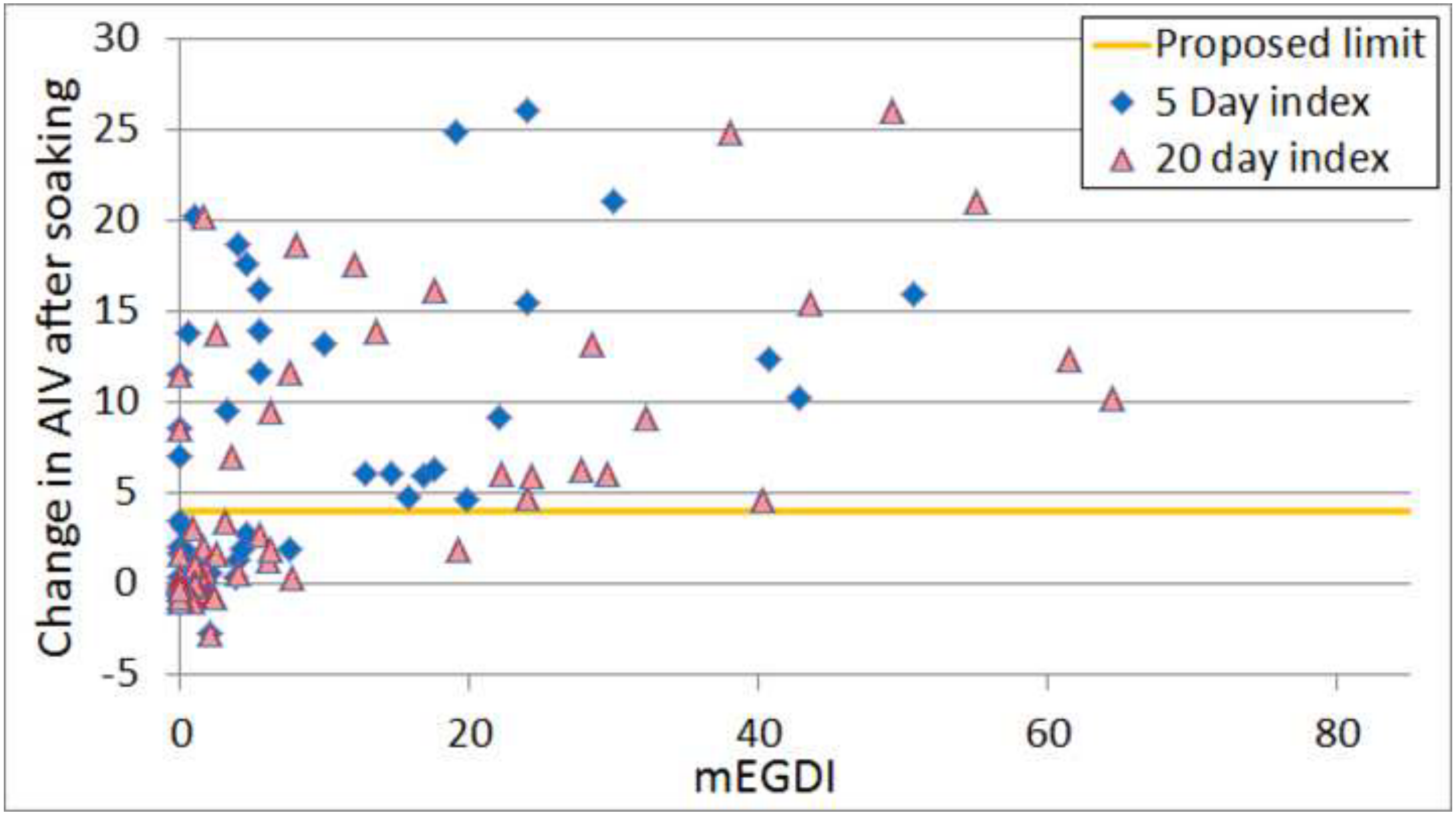

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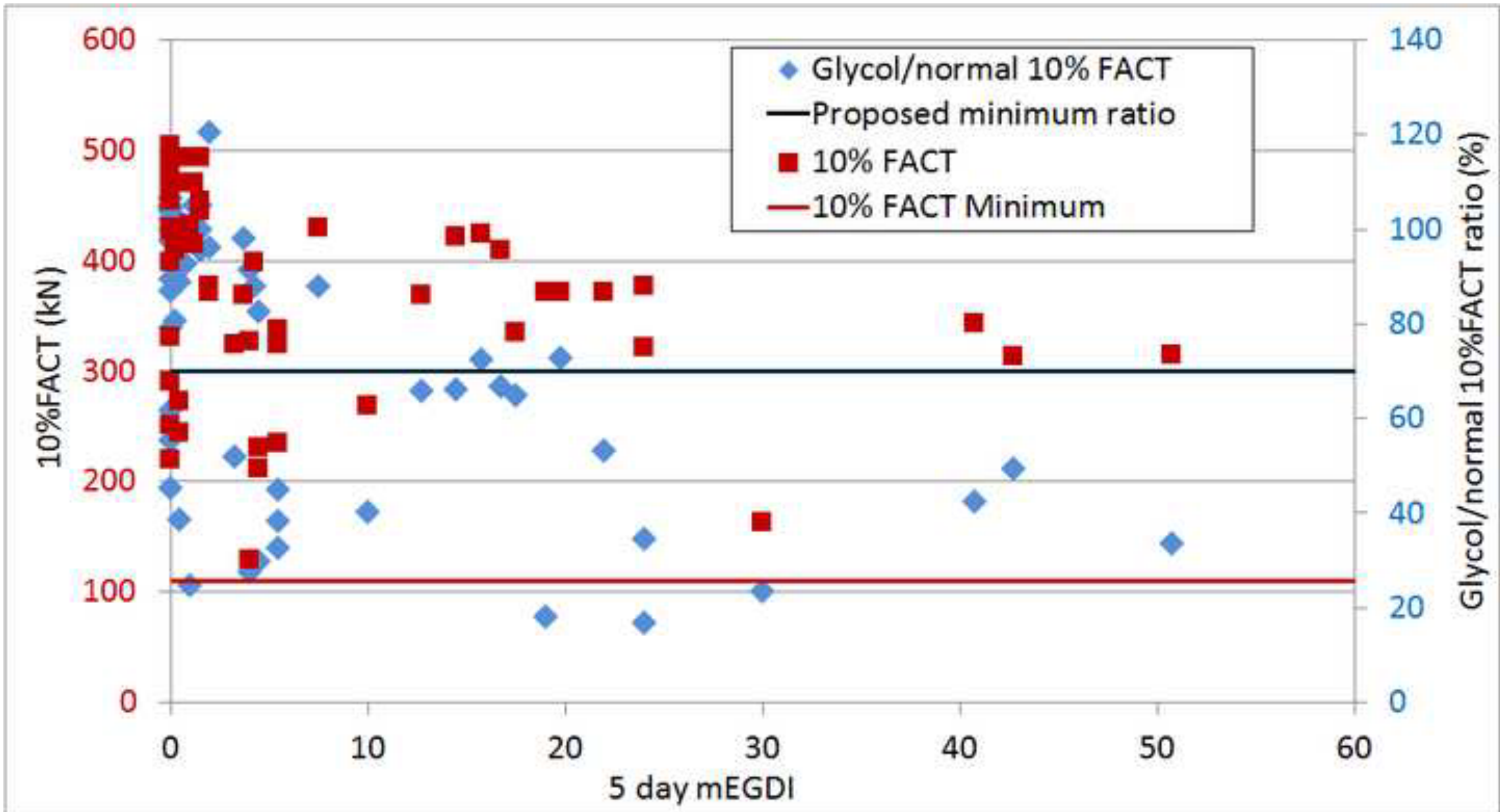

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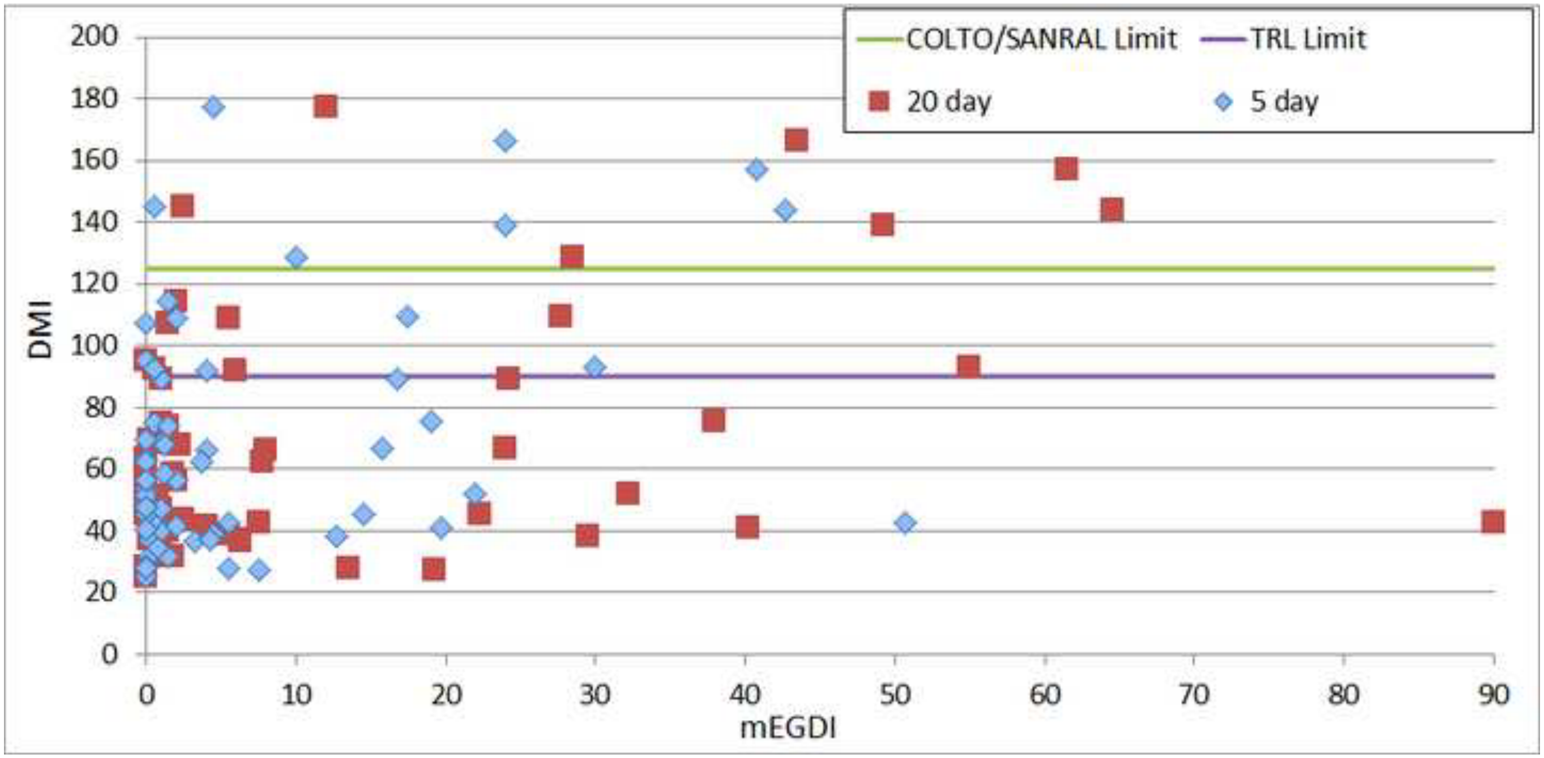

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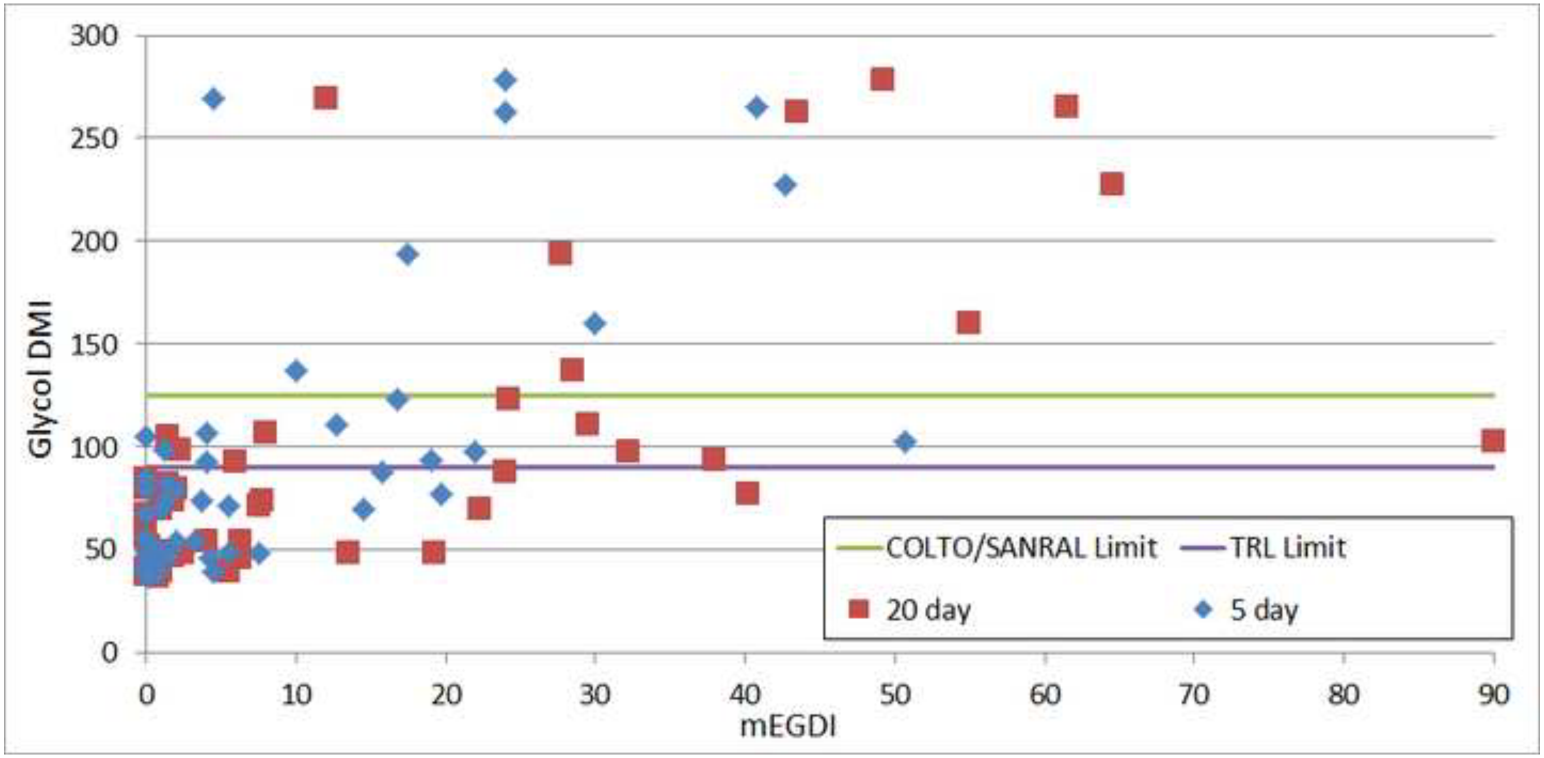

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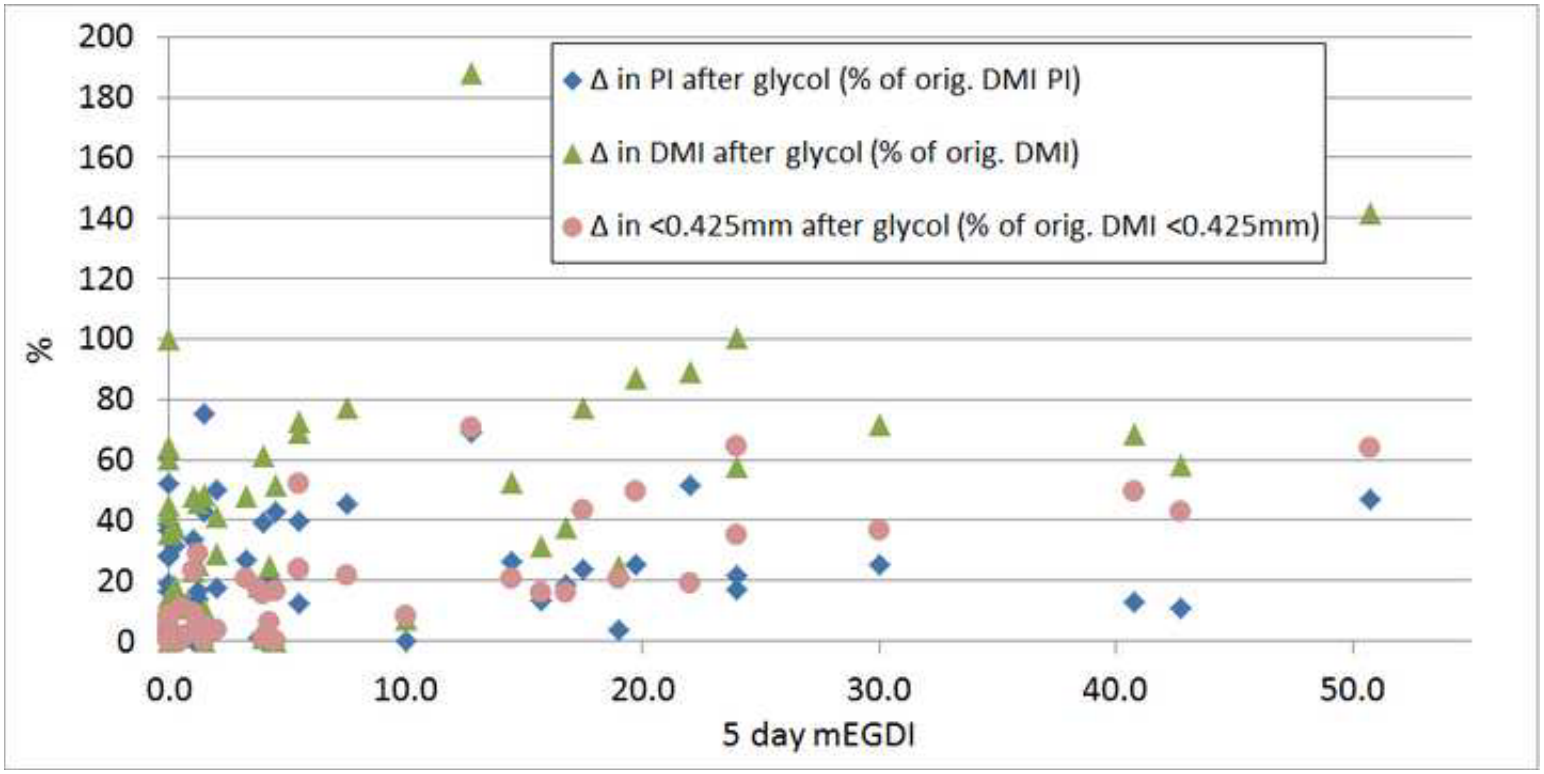

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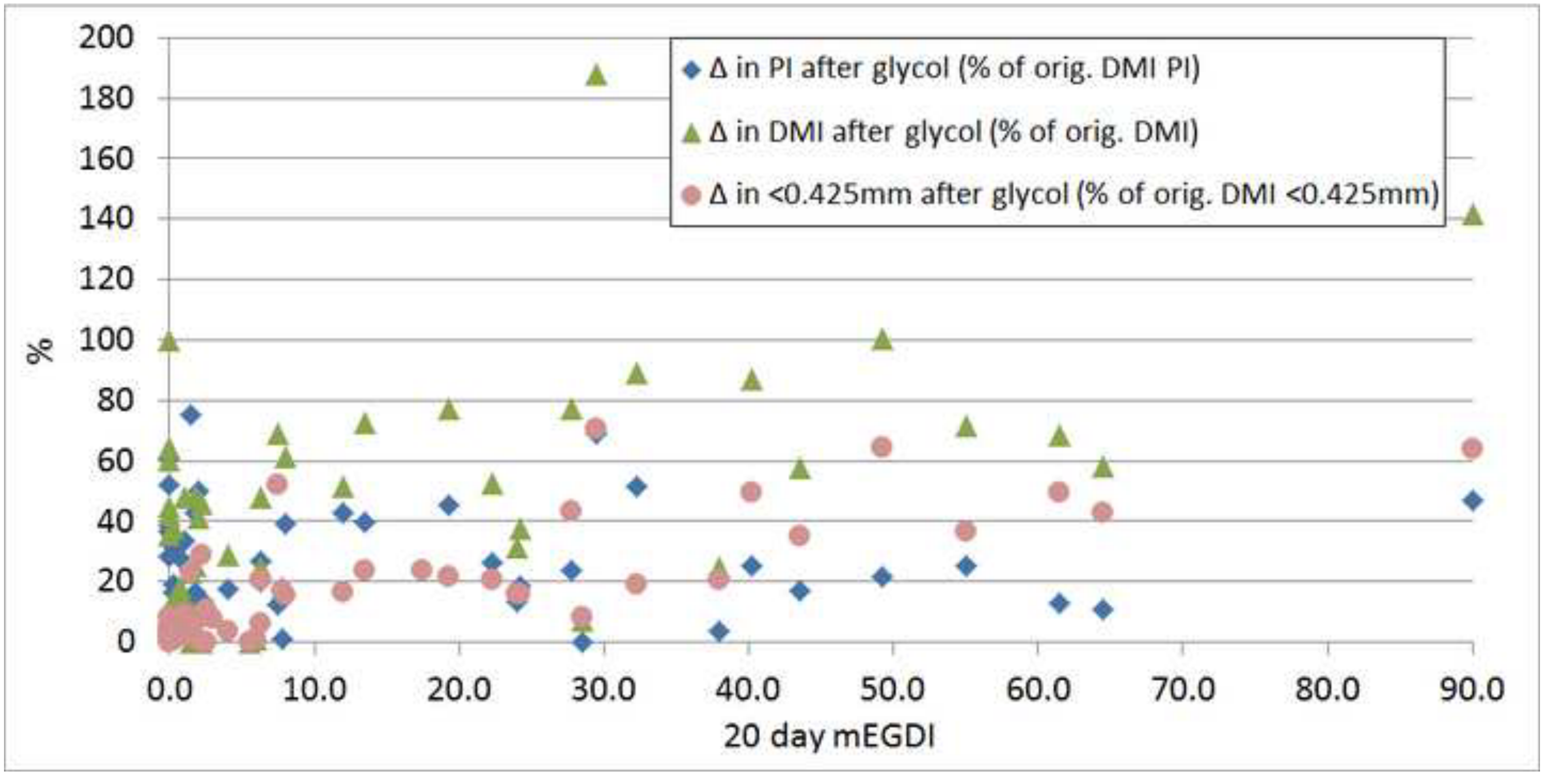

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Table 1. Percentages of tests passed by samples from good and poor performing roads.

Road performance	% of samples passing specified test limits					
	DMI		10% FACT		mEGDI	20/5 mEGDI
	SA*	TRL	SA*	RA*		
Good (n=22)	100	100	100	91	100	100
Poor (n=14)	71	64	100	29	14	7

*SA: COLTO (1988)
*RA: SANRAL

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Table 2. Percentages of tests passed by samples from good and poor performing materials.

Material performance	% of samples passing specified test limits					
	DMI		10% FACT		mEGDI	20/5 mEGDI
	SA*	TRL	SA*	RA*		
Good (n=21)	Defined as 100				95	90
Poor (n=15)	73	67	100	20	27	27

*SA: COLTO (1988)
*RA: SANRAL