Comparison of the polishing resistances of concrete pavement surface textures prepared with different technologies using the Aachen Polishing Machine

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Abstract:

Due to longer durability and lower maintenance costs, concrete pavements are more competitive than asphalt pavements in areas that require rigid pavements. To ensure the surface skid resistance of concrete pavement, thus the driving safety, appropriate textures must be created at the concrete pavement surface. Common surface texturing treatments in Germany include exposed aggregate, grinding and grooving, and sealing methods. In order to investigate the influence of different surface texturing methods on the wearing resistance of concrete pavement, concrete pavement samples with six different surface textures were manufactured. The advanced Aachen Polishing Machine (APM) was adopted in the current study to simulate the different polishing states on the extracted samples with 0, 16, 33, 100, 200, and 300mins of real-tire polishing. After each polishing stage, a series of surface characteristic tests were then applied to evaluate the wearing characteristics of pavement samples. The test results show that different surface textures exhibit the different performance of long-term polishing resistance. Among all the texturing methods investigated, the exposed aggregate and sealing treatments provide the best long-term polishing resistance for plastic and hardened concrete respectively.

The current research provides comprehensive evaluation and significant guidance on the selection of surface treatment methods for new construction of cement pavement and surface maintenance of hardened concrete pavement.

Keywords: Concrete Pavement, Surface Texture, Macro-Texture, Skid Resistance, Polishing Resistance.

1 Introduction

1.1 Concrete Pavement and Surface Texturing

By providing increased mobility for people, goods and services, the road is and will still be the driving force in socio-economic growth and modern civilization (Ivanova. 2003). Asphalt concrete is the most frequently used material in road construction, followed by cement-based concrete (Tayabji et al. 2010). The engineering, economic and environmental properties of asphalt and cement pavements have been extensively studied (Kim et al. 2008; Zapata and Gambatese. 2005). Compared with asphalt, the cement-based pavement possesses benefits, such as high stiffness and loading bearing capacity, rutting resistance, good light-reflection property, low solar radiation adsorption, etc. (Woodward et al. 2013; Delatte. 2008). Additionally, due to the particularities of certain areas, such as the convenience of raw material mining, special requirements for carrying capacity, service climate and environment, etc. concrete pavement is still competitive compared with asphalt pavement, especially in tropical areas such as Hong Kong.

For cement concrete pavement (CCP), the mix design, including cement content, water-to-cement ratio, aggregate-to-cement ratio, aggregate size, etc., possess a significant influence on the mechanical properties. However, the uppermost zone of CCP (**Fig. 1**) consists mainly of cement paste provides the surface functionalities of CCP (FGSV 2000; Dames and Sulten 1982).

The functional properties of CCP (i.e. skid resistance, acoustic properties, drainage capacity etc.) are intrinsically determined by surface texture and material mix design (Jiang et al. 2018; Cackler et al. 2006). Texture information of CCP can be represented by a continuous spectrum of wavelengths and amplitudes obtained utilizing a Fourier Transformation. The surface texture characteristics include micro-texture and macro-texture (Mataei et al. 2016; Wang et al. 2014). The former, with a roughness wavelength below 0.5 mm, is known as the intrinsic surface irregularities of the grains. While the latter describes the unevenness with a wavelength of 0.5-

50 mm, which generally refers to the void area among aggregates (Cackler et al. 2006; Hibbs and Larson. 1996). Studies have shown that macro-textures can not only contribute to the skid resistance but also reduce the hydroplaning of vehicles by dispersing road runoff (Ong et al. 2005)0. Acoustically relevant wavelengths of the texture are between 1 mm and 250 mm – roughly corresponding to the size of tire tread elements and the entire tire-road contact patch. The texture of concrete pavements and the resulting mechanical vibration stimulation of the tire tread depend on the selected material, concrete mixture as well as texturing technique. The texture induced specific air-flow resistivity is another important parameter, which describes how easily air can escape from the tire-road contact patch, and the specific air-flow resistivity represents an important parameter for estimating aerodynamic noise emissions (Beckenbauer et al. 2002).

To achieve the optimum performance of drainage capacity, skid resistance and noise reduction, various surface texturing methods have been developed for CCP. However, despite the existence of a variety of concrete pavement texture technologies, no comprehensive and systematic comparison and summary have been conducted on them. According to the timing of implementation, these texturing methods can be divided into two categories: texturing of plastic concrete and texturing of hardened concrete (Austroads 2009).

1.2 Practices for Texturing Plastic Concrete

Four types of texturing methods are commonly applied to plastic concrete, namely exposed aggregate concrete, drag textures, transverse tining, and longitudinal tining. Among various types of texturing methods for plastic concrete, the dragging and tining methods are commonly used in the US, while the exposed aggregate method is more often used in European countries.

In recent years, the application of Exposed-aggregate Cement Concrete Pavement (EACCP) has been increasingly applied in Europe (Cackler et al. 2006; Skarabis and Stöckert. 2015). EACCP is known as low-noise concrete pavement technology. During construction, a setting retardant is applied to the surface of fresh concrete pavement. The setting of the surface layer is retarded while the hardening of the principal sections is undisturbed. Due to the differentiated setting process, the surface mortar is brushed or washed off, resulting in aggregate exposure (Zhang et al. 2014; Akkari and Izevbekhai. 2012). Studies and engineering practices have demonstrated that EACCP offers a comfortable surface combined with low noise and good skid resistance (Delatte. 2008). High-quality aggregate (aggregate with high polished stone value) is required for the construction of EACCP. Since May 2006, Germany has specified the exposed aggregate technique combined with a two-lift construction process as the standard surfacing method for concrete roads on motorways.

1.3 Practices for Texturing Hardened Concrete

Diamond grinding and grooving of concrete pavements are two types of texturing methods that have been applied to hardened concrete. The original purposes of diamond grinding and grooving were to correct the surface irregularity, increase the skid resistance, and improve the drainage capability of concrete pavements. In the past years, both techniques have been modified and improved for various purposes. In particular, it has been reported that diamond grinding produced various levels of traffic noise reduction benefits, depending on the grinding configuration.

Grinding has been used in the longitudinal direction to rehabilitate existing pavements by restoring smoothness, however, it is also possible to use grinding as an initial texturing method for new pavements since the early 1960s. Diamond grinding blades are fixed to a rotating shaft with a maximum distance of 3 mm to one another and moved over the pavement surface. The distance between the respective grinding wheels is precisely adjusted with smaller spacer wheels mounted in between grinding wheels. The grinding depth is usually only a few millimeters. The resulting texture is defined by the segment arrangement on the shaft (grinding segment width and spacer segments) as well as the properties of the concrete such as material strength and petrographic properties of coarse aggregate. In a study comparing the noise level of the longitudinal ground pavement and that of the transversely tined pavement, it was found that the former was quieter than the later by 2 to 5 dB(A) when the noise was measured on the side of the road (Burgé et al. 2001).

Similar to diamond grinding, diamond grooving is mainly used along the longitudinal direction as a rehabilitation method to improve the drainage of water between the tires and pavement surface, thus improving friction resistance. The decisive difference between grooving to grinding is the distance between the saw blades, which exceeds 10 mm. The manufacturing process of this texturing method is analogous to grinding. In mainland China, diamond grooving has been used to improve the friction resistance of both newly constructed and existing CPPs. It is specified that for newly CCP, diamond grooving should be implemented when concrete has gained at least 40% of its 28-day strength (FGSV 2009), while it is usually done after 21 days in practice.

Grinding and grooving procedures can be applied in combination resulting in an additional production step. In the first step, the surface is processed with conventional grinding followed by grooving. Grinding and grooving are combined when concrete pavements contain aggregate with a low polishing resistance. The grooving texture leads to a long-term increase of skid resistance in this case (Skarabis and Stöckert. 2015).

1.4 Objectives

Numerous studies have been carried out into the surface properties of CCP (i.e. skid resistance, acoustic properties, drainage capacity, etc.) (Wang et al. 2014; Hibbs and Larson. 1996). However, the published information on the long-term development of polishing resistance by different surface texture methods is scarce. For CCP, existing studies are mostly developed based on the impact polishing test, which has a great difference to the actual pavement polishing effect(Wang et al. 2013). Hence, due to the lack of propitiating and systematical evaluation methods, the deterioration mechanism of skid resistance in CCP can be hardly demonstrated.

In order to further illustrate the deterioration characteristics of CCP texture, different types of surface texturing methods in Germany, including exposed aggregate, grinding and grooving and sealing methods were selected in the present research. The long-term polishing behavior of pavement surface under traffic load was simulated by Aachen Polishing Machine (APM) developed by the Institute of Highway Engineering (ISAC) at RWTH Aachen University. The actual wearing of the road surface can be achieved by APM with the integration of real tires, traffic load and wearing conditions (moisture and wearing agent). The feasibility and accuracy of this method have been widely proven (Wang et al. 2014; Ueckermann et al. 2015; Wang et al. 2015). During each polishing process, both the macro and micro-texture indexes were calculated, and the regression analysis was conducted to provide a precise basis for evaluation. The texture characteristics affect the road surface function such as skid resistance, noise, and drainage, and therefore serves as an indicator for judging the wear resistance of the road surface.

2 Material and Methods

In order to systematically and comprehensively study the texturing characteristics of CCP, the research was conducted on the texturing methods for both plastic and hardened concrete. For both surfaces, there are traditional methods and new texturing methods. In the current study, a total of six different texture methods have been investigated.

2.1 Testing Samples of Texturing Plastic Concrete

To investigate the wearing resistance of concrete pavement under different surface texturing methods, a full-scale concrete pavement slab with four different textures was first built following the adopted construction specification. For newly constructed pavement, two types of EACCP (V1&V2) as shown in **Fig. 2**.

The CCP used to build panels V1 and V2 had a grade of C40/10, which is conventionally used in Germany, which has shown that CCP with smaller aggregate size produces better skid and acoustic performance when the exposing aggregate texturing method is used. **Table 1** shows the batching proportions for C40/10 used in this study. The design slump values for both CCP mixtures were 80.

After the concrete panels were hardened, four pairs of 240mm-diameter cores were extracted from the panels with different surface textures for the following surface characteristics testing. The main purpose of this study was to evaluate the surface characteristics. The dramatic changes in surface properties make these samples very convincing to determine the effects of different surface treatments on polishing and friction behavior.

2.2 Test Samples of Texturing Hardened Concrete

For pavements that have been in use for many years, grinding and grooving are generally the traditional way to restore texture. The recommendations in (Beckenbauer. 2006)0 state that diamond blade stacks are arranged to provide a flush ground surface as well as longitudinal grooves. The blades used to produce the flush ground surface shall be flat across their contact surface and in the same plane with other flush grind blades (excluding grooving blades) when mounted.

Based on the research projects of NGCS (Scofield et al. 2010; Beckenbauer. 2006), the optimized grinding texture (V3), as well as a combined grinding and grooving texture (V4), are resulted, as seen in **Table 2**.

The grinding texture samples (V3) were made with a laboratory grinding machine, as shown in **Fig. 3**. The machine consists of a saw head, which can hold a sheet packet of standard saw blades and spacers up to a width of 30 mm. This allows an arrangement of a maximum of seven saw blades, between which the spacers are arranged. The diameter of the saw blades is 350 mm, and the space between each saw is 200 mm. The saw head is driven at a speed of 2800 rpm, with cutting depths of up to 10 mm can be achieved. Below the saw head, the concrete specimen is placed on a mobile table. For texturing the V3 specimen, the saw head is first lowered manually to the desired depth of cut. By using the position indicator, the cutting depth can be adjusted with a tenth of millimeter accuracy. By adjusting the distance between saw blades following table two, the V4 specimen can also be manufactured.

The concrete surfaces can also be treated by the epoxy sealing method (V5 & V6), which treatment can be demonstrated in the following steps. Firstly, the epoxy resin is mechanically metered, mixed, and applied to the concrete surface (**Fig. 4**, a). Then, the various broken chippings of the size 2–5 mm are spread and pressed across the surface (**Fig. 4**, b). The amount of binder should be selected so that the chippings are embedded to about half of their diameter. After hardening, the excess chippings are swept away. The example samples of concrete pavement material based on epoxy resin sealing can be seen in **Fig. 5**. Based on different aggregate sizes, the V5 (2/3 mm) and V6 (3/5 mm) samples applied in the current research are manufactured.

2.3 Surface Characteristics Tests

In order to characterize the profile depth of the sample surface during the polishing process, a profilometer was applied (Wang et al. 2015). Based on non-contact high-resolution optical metrology tools and chromatic white light sensor, the profile depth of the sample surface can be accurately measured. The device equipped a vertical scanning range of 50 mm and a horizontal measurement range of 200 mm × 200 mm.

For the current research, a resolution of 100 μm in the area rage of 100 × 100 mm was selected, which can roughly simulate the contact area between the tire and the pavement surface. In the measuring area, a total of one million data points of surface depth was recorded, based on which data, a three-dimensional image of surface texture, can be established (**Fig. 6**).

According to ISO 13473-1:1997, the surface characteristics of pavement can be evaluated by mean profile depth (MPD) and estimated texture depth (ETD). Where,

$$\mathrm{ETD} = 0.2\ \mathrm{mm} + 0.8\ \mathrm{MPD} \tag{1}$$

The ETD value can be equated with the MTD value of the manual volumetric test methods.

2.4 Wearing Test Using Aachen Polishing Machine (APM)

The limitation of conventional polishing approaches, such as the PSV or W/S tests, is not equivalent to the real tires polishing. Heence, an advanced real-tire polishing simulator named Aachen Polishing Machine (APM) was designed and assembled by the Institute of Highway Engineering (ISAC) at RWTH Aachen University. Based on extensive previous research (Wang et al. 2014; Wang et al. 2016), APM is a laboratory experiment that can simulate the long-term polishing effect of the actual conditions.

As shown in Fig. 7, the polishing effect of APM is mainly achieved through two real vehicle tires (Tire type: Continental, 165/75 R 14 C 8PR 97/95 R TL). During the polishing process, the tire will move back and forth horizontally at nine times per minute, and the tires will self-rotate at 41 times per minute while the sled is moving. By spreading the standard polishing agent and water over the CCP surface evenly at a rate of 27 ± 7 g/min, the APM can simulate the most unfavorable shear state of the pavement surface (Lu et al. 2019). For the current test, the load induced by a tire with an inner pressure of 0.4 MPa and an imposed load of 400 kg is applied on the CCP surfaces (Wang et al. 2014).

2.5 Testing procedures

To simulate the tire-polishing condition, concrete plates with 32 cm x 26 cm x 4 cm were manufactured for the APM test. The polishing process was applied in six stages, with polishing times of 0, 16.7, 33.3, 100, 200 and 300 minutes, respectively. After every polishing process, the friction and texture characteristics, including BPN (British Pendulum Number, measured by the pendulum test device following DIN EN 13036-4), MPD (Mean Profile Depth) and ETD values (Estimated Texture Depth) are determined. The test scheme is shown in **Fig. 8.**

3 Results and Analysis

3.1 Visual Inspection

The most basic evaluation of the changes induced by the polishing process can be made by visually inspecting the macro-texture of a specimen. The surface treatment with exposed aggregates (V1&V2) showed much fewer alterations of its initial state. This is mainly due to the protruding aggregates that have much higher polishing and wearing resistances than the mortar. The surface treatments with grinding and grooving (V3 and V4) showed fewer alterations of their initial states. While for the sealing method (V5 and V6), the variation of the surface between the final and initial polishing state was not very obvious.

3.2 Texture Measurement

As can be seen from **Fig. 9**, it illustrates the development of the measured ETD of the test specimens during the polishing process. The MPD, which is equivalent to the ETD value measured by the volumetric method, showed a similar trend against the polishing duration. The MPD of all specimens decreased at decreasing rates with polishing. The major decrease of the macro-texture occurred within the first 30mins, which means at the beginning state of open traffic, the filler and fine aggregates on the concrete pavement surface could be worn out. The macro-texture of the concrete pavement is mainly composed of aggregate with a large particle size after the beginning state of open traffic, and it does not change greatly with further polishing.

Among six variants of newly constructed surface texture, sealing (V5 & V6) exhibited the best results with the least decrease in MPD as well as the highest final value after 300 min polishing. Followed by the grinding and grooving (V4) and exposed aggregate method (V1 &

V2), while the grinding treatment (V3) showed the lowest value. This is also consistent with the visual appearance. For the V3 and V4 variables that simulate the road maintenance process, there is almost no change in V3, while V4 has a similar process to other variants. It is because that the macro-texture of the road surface is inherently weak based on the treatment by grinding, so even if the polishing time increases, there will be no obvious changes.

As can be seen from **Fig. 10**, in earlier polishing states, both V1 and V2 showed a significant reduction of ETD among six surface treatment methods. However, for the long-term polishing duration, the dramatic decrease can be only observed in V2. It implies that pavement surfaces treated by exposed aggregate are more likely to experience a relatively high decrease of macro-texture in the earlier polishing stage. As for the long-term polishing process, the aggregate types play a more important role in the development of the macro-texture of the pavement surface. Based on the results shown in the figure, it can be noted that sealing shows the best durability of macro surface texture both in earlier and long-term polishing stages. It can be also noticed that the macro-texture accounts for more importance on the skid resistance of concrete pavement.

To mathematically explain the development of macro-texture indicator (ETD) of concrete pavement surfaces during the polishing process, a prediction model concerning the polishing time is developed in the previous research(Wang et al. 2013;Ueckermann et al. 2015). This model defined the overall ETD:

$$\mu(t) = A + B\exp(-t/C) \tag{2}$$

The parameter A describes the fluctuation amplitude of macro-texture in the final state. B is the difference of ETD between the final state and initial state. C depicts the changing rate of macro-textures. By fitting the ETD results concerning equation (1), the fitting curves of six types of concrete pavement surfaces are shown in **Table 3**.

It can be known that the application of different surface types affects the three parameters in the prediction model, especially on the parameter A and B, which determine the initial value. The lowest ETD was demonstrated by the surface treatment of V3, while the treatment of sealing showed the best durability.

3.3 Skid resistance measurement

The BPN value of six types of surface treatment can be illustrated in terms of the polishing duration (Fig. 11). All the specimens showed a downward trend during the initial polishing stage. The largest initial decrease was shown in V3 and V4, which had a relatively high initial polishing value, but after the earlier polishing stage, the surface mortar was almost worn off. In this case, with the increasing of polishing duration, the decreases of BPN in V3 and V4 were not evident. Differently, the BPN value of V5 and V6 only dropped moderately after the earlier polishing stage. As the polishing time increases, the BPN value is also decreasing accordingly, but the decreasing rate of long-term polishing is much slower than the initial stage. Regarding the surface treatment on plastic CCP, the selection of different types of aggregates can largely influence the skid resistance properties. Throughout the polishing duration, the EACCP with granite only experienced a decrease in the earlier stage. However, the EACCP with basalt experienced a continued decline in the long-term polishing, though the earlier loss of BPN was not obvious.

Based on the chart of a reduction rate of BPN (in **Fig. 12**), the texturing methods on hardened concrete, the reduction rates of sealing methods are generally higher than grinding and grooving while for the texturing method on plastic concrete, the EACCP based on granite has a better long-term polishing resistance when comparing to the method based on basalt.

3.4 SCRIM analysis

For comprehensively evaluating the micro- and macro-texturing evaluations, a Sidewayforce Coefficient Routine Investigation Machine-values (SCRIM) method was proposed. The British pendulum tester (BPT) is used in the measurement of BPN values of pavement surfaces. The test device measures low-speed friction (about 10 km/h) and is commonly used to assess the micro-texture of pavement surfaces. Since the BPN measurements are conducted at 10 km/h, a conversion of values to a relevant speed range is necessary. It was described that an operation can convert BPN values into SCRIM values, which represent skid resistance coefficient at the speed of 60 km/h shown in the following (Wang et al. 2015):

$$\mu_{SCRIM} = 0.0189 \cdot BPN - 0.3118 - \sum \Delta\mu_i \cdot V \quad (3)$$

Where,

μ_{SCRIM} = Sideways Force Coefficient as measured by the SCRIM device at 60km/h;

BPN =Pendulum value based on BPT tester, in which a rubber slider of the Federal Institute for Materials Research and Testing, Germany, is used (international rubber hardness degree according to DIN 53505: (60 ± 2) Shore A);

$\Delta\mu_i$ = correction factor depending on the measuring speed and concrete surface treatment determined based on the empiric values (Wang et al. 2015)

V = Speed of skid resistance measurement.

By applying the conversion method described above, the skid resistance coefficient μ_{SCRIM} at 60km/h can be calculated as shown in **Fig. 13**. The overall trend is similar to the changes in BPN and ETD, both in the initial polishing stage, experienced a very large decline, and continued to decline slightly during the long-term polishing period and eventually stabilized. Among all the test samples, the sealing method still exhibited the best skid resistance and wear resistance performance along with the whole polishing duration. Specifically, in the initial polishing stage, the μ_{SCRIM} of the sealing method does not decrease much, and the decreasing rate of μ_{SCRIM} in the later polishing stage is lower than the earlier polishing stage. This is mainly due to the contribution of epoxy's bonding strength provided during sealing, which prevents the aggregate to be worn off by polishing effect. Following the sealing method, the grind and grooving and exposed aggregate treatment by granite show the relevant higher durability of surface texturing characteristics when comparing to exposed aggregate treatment by basalt and the grinding method, which presents the lowest durability of skid resistance among the selected methods. This is mainly due to the contribution of grooving to the improvement of the macro-texture of the surface, which makes the road surface exhibits a better friction coefficient at high speeds. Regarding the exposed aggregate treatment, the type of aggregate plays a significant role in the durability of pavement surface characteristics.

The reduction rate of the comprehensive evaluation of surface texture by considering both micro- and macro-texture characteristics can be seen in **Fig. 14**. It can be seen that both grinding and grinding and grooving show the largest decrease in the earlier polishing state. In the final polishing state, the largest decrease was observed in the treatments of grinding and exposed aggregate by basalt.

4 Conclusions

In this study, the macro-texture of six types of CCP surface textures were characterized through laboratory testing. The major findings of this study can be concluded as follows:

- Among the texturing methods for plastic concrete pavement evaluated in this study, the method of exposing aggregate is still recommended due to its relatively high polishing resistance in terms of both macro and micro-texture characteristics. Additionally, it is also suggested to select aggregates with high polishing resistance when constructing the EACCP.
- For hardened concrete pavement surfaces, grinding and grooving are very common and mature methods. However, these two methods have a very large decrease in both ETD and BPN values in the initial polishing state. This is because after polishing, the cement mortar of the concrete road surface will be quickly worn away. Therefore,

after the initial polishing, the texture of the surface texture is also affected by the aggregate texture characteristics in addition to the artificial grinding and grooving.

- Based on the results, as a novel texturing method on the hardened concrete pavement surface, the sealing method showed higher durability of surface textures both in the earlier and final polishing stages, which indicates that this method has a good capability of long-term polishing resistance.

In considering the above findings, long-term measurements showed that all surface treatment methods exhibit surface roughness which decreases over the polishing duration and converges toward their final value. It can be also concluded that exposed aggregate and sealing methods have a very high potential to provide improved surface characteristics in terms of macro- and micro-texture in comparison to other surface textures adopted in plastic and hardened concrete pavement respectively.

However, due to the limitation of testing methods, another significant surface property of concrete pavement, the noise evaluation of different texturing methods was not comprehensively studied. Further investigation on the texturing methods is also required to consider more inflicting factors such as noise absorption coefficient, temperature, freeze-thaw-alternatives, the wheel load, the tire characteristics and the life cycle analysis. Besides, the interaction between various impact parameters needs to be integrated to explain the periodical fluctuation of the surface texture. The polishing effect simulated by APM should be further validated by the practical examination of long-term development.

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6 Data Availability Statement

All data, models, and code generated or used during the study appear in the published article.

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Table 1 Batch Proportions of PCC (kg/m^3)

Mix	C40/10
Cement	330
Pulverized Fuel Ash	110
20mm	725
10mm	345
Fines	620
Water	185
Aggregate Cement Ratio	3.84
Water Cement Ratio	0.42

Table 2 Recommended grinding and grooving textures for noise reductions

Texture	Grinding			Grooving		
	Segment [mm]	Spacer [mm]	Depth [mm]	Segment [mm]	Spacer [mm]	Depth [mm]
V3	2.4	1.0	4.0	-	-	-
V4	3.0	1.0	2.0	3.2	15.0	3.5

Table 3 Fitting curves of concrete pavement surface polishing behavior

Type of fine aggregate	Fitting equation	R^2
V1	$ETD = 0.690+0.312 \cdot e^{(-t/18.109)}$	0.901
V2	$ETD = 0.990+0.072 \cdot e^{(-t/29.103)}$	0.947
V3	$ETD = 0.369+0.048 \cdot e^{(-t/68.639)}$	0.984
V4	$ETD = 1.174+0.420 \cdot e^{(-t/39.023)}$	0.999
V5	$ETD = 1.78+0.305 \cdot e^{(-t/29.508)}$	0.956
V6	$ETD = 2.03+0.378 \cdot e^{(-t/27.223)}$	0.943