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Comparative Statistical Analysis of Geotextile Tensile Strength Using Wide-Width Strip and Grab Test for Soil Reinforcement Applications

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Abstract. The objectives of this study were to compile a database of geotextiles, test for differences in parameter values between the two methods, and develop a regression model to predict Strip Test values from Grab Test data. This study employed a quantitative approach using local products data, global products for comparison, raw test data, standards, and documents from other countries. Statistical analysis used analysis of variance and boxplots due to the wide variation in the commercial data. The findings of this study confirmed that the Wide-Width Strip Test method per ASTM D4595 produces more precise, consistent, and relevant tensile strength data than the Grab Test per ASTM D4632. The Grab/Strip ratio measured ranged from 1.13 to 6.40 and was not constant. The Strip coefficient of variation of 2.4% was almost half that of the Grab at 5.4%. Woven PET has been shown to have a 48% higher tensile strength and <25% lower elongation than woven PP at the same nominal strength, due to the stiffness of PET's aromatic chains. This study proves that there is no universal conversion factor between the two methods. Mandatory soil reinforcement project specifications require ASTM D4595 or ISO 10319 Strip data.

Keywords: Geotextile, Tensile Strength, Grab/Strip Ratio, Grab test, Strip test

INTRODUCTION

Geotextiles are a type of geosynthetic material that has become an integral part of modern geotechnical engineering. By definition, a geotextile is a permeable textile material used in conjunction with soil, rock, or other geotechnical materials as an integral part of a man-made structure or system. Its primary advantages include cost-effectiveness, durability, and ease of field application, leading to rapid growth in use over the past two decades and making it a key material in new road designs and maintenance programs [1].

In civil engineering practice, geotextiles perform at least seven primary functions: separation, filtration, drainage, reinforcement, stabilization, barrier, and erosion protection. These functions make geotextiles highly versatile. For example, in road and embankment applications, geotextiles are installed as a reinforcement and separation layer to prevent aggregate from mixing with the soft subgrade. As a result, soil bearing capacity is increased, and structural deformation is significantly reduced. In retaining walls and slope construction, geotextiles act as tensile elements that resist soil shear forces, thereby increasing the structural safety factor. Studies on slope design using geotextile reinforcement have shown improved safety factor variations against vertical loads, groundwater levels, and earthquake loads [2-3].

In addition to reinforcement, geotextile filtration and drainage functions have been proven effective in preventing the migration of fine particles while still allowing water to drain. This is crucial for maintaining the subgrade's structural integrity and increasing drainage capacity. In expansive soils, geotextiles can reduce swelling pressure and improve bearing capacity. The use of geotextiles has also been shown to extend the life of infrastructure, reduce maintenance costs, and support more sustainable construction practices [4-5].

The history of geotextile use dates back to 1956, when sand-filled nylon bags were used on the Dutch Delta Works project. Over the past 60 years, their applications have expanded to nearly all fields of civil engineering, geotechnical engineering, environmental engineering, and hydraulics. The global geotextile market has also grown significantly, primarily due to increasing awareness of the benefits they provide in road construction and erosion control [6].

Recent developments have led to the development of natural, intelligent, and high-performance geotextiles. Natural geotextiles made from jute, coir, ramie, and coconut fiber are gaining popularity due to their green approach, reduced environmental pollution, and ability to decompose into fertilizer after their useful life. These natural fibers have a water retention capacity of up to 500% in dry soil conditions, effectively preventing erosion and encouraging grass growth on riverbanks. Synthetic geotextiles made from polypropylene and polyester remain dominant due to their high tensile strength, modulus, and chemical resistance [7].

Geotextiles have evolved from supplementary materials to primary design components considered in structural calculations. Their use has been shown to improve soil stability, drainage capacity, and erosion resistance, while preventing material mixing, and to offer the advantages of durability, cost-effectiveness, and environmental friendliness [8].

In the design of soil reinforcement with geotextiles, tensile strength is a key variable determining the stability and safety of the structure. A specific problem that often arises in the field is the inconsistency in the use of tensile test data, particularly between two commonly used test methods: the Grab Test (ASTM D4632) and the Wide-Width Strip Test (ASTM D4595). These two methods produce significantly different tensile strength values, so errors in their interpretation and application can result in unsafe or, conversely, wasteful designs [9-12].

The Grab Test clamps a geotextile sample to only 25 mm in the center of a 100 mm-wide sample. As a result, fibers outside the clamped area also support the load, providing a "pseudo-reinforcement" effect known as the clamping effect or necking restraint. In contrast, the Strip Test/Wide-Width Test clamps the entire sample width (typically 200 mm) so that all fibers in the cross-section receive the load evenly. This condition better represents the behavior of geotextiles in the field, which are loaded broadly under plane strain conditions.

Due to the difference in loading mechanisms, the strength values from the Grab Test are always higher than those from the Strip Test for the same material. Research shows that the Grab-to-Strip strength ratio can range from 1.5 to 4 times greater, depending on the type and structure of the geotextile. The Grab Test produces values in N or lbf, while the Strip Test produces tensile strength per unit width in kN/m or lbs/in, which are direct design parameters.

Soil reinforcement design standards such as FHWA-NHI-10-024 and the Highways guidelines explicitly require the use of ASTM D4595 Wide-Width Tensile Strength data as the basis for calculations. This is because the failure mechanism of reinforced embankments or slopes involves mobilizing the geotextile's tensile strength across the entire width of the slip plane. If planners use higher Grab Test data, the allowable tensile strength of the tallow will be overestimated. Consequently, the number of geotextile layers may be less than required, the vertical distance between layers may be too large, or the actual safety factor may be significantly lower than planned. This condition increases the risk of excessive deformation and collapse.

Conversely, from the supplier's perspective, Grab Test data is often displayed in brochures because the values appear larger and more commercially attractive. Contractors who don't understand this difference can potentially mis-specify materials, ordering materials based on Grab values when the design requirement is for Strips. This error is still common in district roads and small-scale retaining wall projects.

In addition to the ultimate strength value, the elongation at break parameter also differs. Grab Tests tend to yield lower elongation due to the clamping effect, while Strip Tests yield the material's actual elongation. For reinforcement, the ideal design elongation is low, <10-12%, to control embankment deformation. Therefore, elongation data from Strip Tests is also crucial.

The main problem is not the method but the inappropriate application. Grab tests are suitable for factory quality control due to their speed and cost-effectiveness, as well as for non-structural separation/filtration applications. However, for soil reinforcement design, the only valid data is the strip test. Incorrect use of this data is a major source of discrepancies between the design and field performance of geotextiles as reinforcement elements.

International literature over the past two decades has extensively examined the mechanical behavior of geotextiles, particularly the fundamental differences between the Grab Test and the Wide-Width Strip Test. A synthesis of these studies demonstrates a scientific consensus on the superiority of the Strip Test for design, but also reveals limitations of existing research.

Koerner (2012), in his reference book "Designing with Geosynthetics," asserts that the ASTM D4632 Grab Test measures only the combined strength of fibers clamped at 25 mm and the effects of side fiber contributions, so the results do not represent field conditions. In contrast, the ASTM D4595 Wide-Width Test clamps a 200 mm-wide sample and provides tensile strength per unit width in kN/m, consistent with the plane-strain assumptions in stability analysis. Numerous researchers have quantified this difference. Comparative studies indicate a Grab/Strip strength ratio of 1.36–1.68 for woven PP geotextiles, and can be higher for non-wovens due to the dominant necking effect.

The FHWA-NHI-10-024 document normatively prohibits the use of Grab data for the design of Mechanically Stabilized Earth Walls (MSE Walls) and reinforced slopes. Reduction factors for creep, installation damage, and degradation are all calibrated against Wide-Width data. Holtz et al. (1998) in their Geosynthetic Design and Construction Guidelines also state that design parameters such as Tult and tensile modulus must be derived from Strip Tests to be compatible with Limit Equilibrium and FEM methods [13].

Several studies have attempted to establish empirical Grab-Strip correlations for rapid estimation purposes. However, the general conclusion is that these correlations are highly dependent on polymer type, weave structure, grammage, and fiber direction, and therefore cannot be generalized. Correlation attempts often fail due to high product variability. Therefore, ASTM and ISO have never released official conversion factors [14].

Recent research by Wu et al. (2020) reviewed geotextile innovations, including natural geotextiles made from jute and coir. They found that test data inconsistency also occurs with natural fibers and is even more severe due to the variability of fiber properties.

Most databases and comparative studies on Grab vs. Strip have been conducted on conventional PP and PET woven/non-woven geotextiles. Data for high-performance geotextiles, geocomposites, or natural geotextiles is still limited. However, the non-uniform fiber interaction mechanisms in natural geotextiles may result in different behavior during the Grab test.

Standard Strip Tests are conducted at a strain rate of 10%/minute. Meanwhile, the load on soil reinforcement is long-term. The literature still lacks data on the relationship between the short-term tensile strength of the Strip Test and creep behavior over 75-100 years. Koerner (2012) acknowledged that the creep reduction factor (RFCR) is still based on extrapolation and many assumptions.

Most tests are conducted in a dry laboratory at 21°C. Studies on the effects of moisture content, soil confinement, compaction damage, and field temperature on the Grab/Strip strength ratio remain sporadic. Berg et al. (2009) stated that the RFID factor is highly site-specific, but there is no standardized test protocol that can accurately predict it for all types of local aggregates.

Although the technical literature is clear, field surveys by several authors indicate that many practitioners in developing countries still specify geotextiles based on Grab data due to limited access to Strip tests or a lack of understanding. The literature on knowledge dissemination and case studies of failures resulting from these errors remains limited.

The literature has established that the Strip Test is the standard for reinforcement design, while the Grab Test is for Quality Control. However, limitations exist in generalizing the data to new materials, long-term prediction, and knowledge transfer to practitioners. This gap justifies further research that focuses on: 1) Local/natural geotextile Strip Test Database, 2) Accelerated creep test, and 3) Preparation of practical specification selection guidelines for consultants and contractors.

Although international literature has emphasized the conceptual and procedural differences between the Grab Test ASTM D4632 and the Wide-Width Strip Test ASTM D4595, a critical review of publications from the past 10 years reveals a significant research gap: the lack of a comprehensive, standardized, and representative statistically based comparative evaluation of product variations in the market.

Most existing references, including the textbook Koerner (2012) and the FHWA-NHI-10-024 guide (Berg et al., 2009), describe and normatively evaluate the differences between the two methods. The comparative data presented generally consist of single samples or average ratios from a limited number of samples. Rawal & Saraswat (2011) concluded in their review that Grab-Strip correlation efforts failed due to high variability. Still, they did not include statistical meta-analysis to quantify the extent of this variability or the most dominant factors influencing it.

To date, no study has compiled a large database of Grab and Strip test results from various manufacturers, polymer types, weave structures, and grammages, and then analyzed them using ANOVA, multivariate regression, or probability distribution analysis. Consequently, practitioners lack quantitative guidance on how inaccurate Grab data should be, if necessary, or what a reasonable coefficient of variation is for each geotextile type. This is crucial for risk analysis on projects with limited data availability.

ASTM D4595 and D4632 prescribe test procedures, but there are no published large-scale round-robin tests specifically for geotextiles that evaluate the repeatability and reproducibility of both methods. For other materials, such as steel or concrete, inter-laboratory statistical studies are common. In geotextiles, questions such as "Is the standard deviation of the Strip Test results smaller than the Grab Test?" or "Does the operator significantly influence the Grab Test due to the jaw break effect?" have not been statistically answered. This lack of data makes estimating design uncertainty difficult.

The existing literature, including the review by Wu et al. (2020), focuses on commercial PP/PET geotextiles. Meanwhile, the development of natural geotextiles from jute, coir, coconut fiber, or local Indonesian products has not been accompanied by an adequate comparative test database. The non-uniform characteristics of natural fibers in diameter, length, and strength are expected to increase the data scatter in the Grab Test compared to the Strip Test. However, this hypothesis has not been tested using factorial experimental designs and statistical tests. Without such data, the potential of local geotextiles for reinforcement cannot be scientifically validated in accordance with modern design principles.

Reinforcement designs use reduction factors (RFID, RFCR, and RFD), largely derived from FHWA guidance based on North American data from the 1990s. Koerner (2012) refers to these values as conservative "guidelines." No public studies have yet conducted back-analyses of projects in Southeast Asia to validate the statistical distribution of actual reduction factors in the field. Case history-based analysis using Bayesian or Monte Carlo methods can narrow the range of conservatism, but this research gap remains unfilled.

This gap raises three practical issues: 1) The potential for costly overdesign due to the lack of statistical data for safety factor optimization; 2) The risk of underdesign in small projects that only have Grab data from brochures; and 3) Obstacles to certification of geotextile products by local MSMEs due to the high cost of strip testing without risk-based statistical justification. Therefore, future research needs to address this gap by: 1) Developing an open database of Grab and Strip test results from at least 100 product variants with replications, 2) Statistical analysis to model relationships, variability, and confidence intervals, 3) Inter-laboratory testing to establish method precision, and 4) Developing a probabilistic design framework for geotextile reinforcement.

This research aims to address the scientific gap in the comparative evaluation of the Grab Test and Wide-Width Strip Test geotextile tensile testing methods through a comprehensive statistical approach representative of conditions in Indonesia. Specifically, the research objectives are outlined below.

The primary objective is to compile a geotextile tensile-strength database that includes the ASTM D4632 Grab and ASTM D4595 Strip methods for various materials commonly used in Indonesia, including woven polypropylene, woven polyester, nonwoven, and natural geotextiles made from jute/coconut fiber. This database is important because existing literature, such as Koerner (2012) and FHWA-NHI-10-024, does not provide data on local product variability, making design validation for domestic projects difficult.

This study aims to test the significance of differences in tensile strength, elongation, and modulus values between the two methods using factorial analysis of variance. Furthermore, the study will measure precision through repeatability and reproducibility between laboratories, in accordance with ASTM E691. This addresses the limitations mentioned by Rawal & Saraswat (2011): the Grab-Strip correlation is difficult to determine due to high variability and has never been statistically quantified.

The third objective is to formulate a regression model to predict Strip Test values from Grab Test data, complete with 95% confidence intervals. This model is expected to provide quantitative guidance to consultants and contractors on small-scale projects, which often have only Grab-based brochure data. This probabilistic approach adopts reliability-based design recommendations increasingly promoted in modern geotechnics.

The study aims to identify how polymer type, weave structure, grammage, and fiber direction influence the Grab/Strip ratio. This result is crucial because Wu et al. (2020) showed that natural geotextiles have different mechanical behaviors, but standardized comparative test data are lacking.

The ultimate goal is to produce technical guidelines that can be adopted by agencies such as the Highways Authority (Bina Marga), including limitations on the use of Grab data, risk-based interim correction procedures, and proposed witness-testing requirements for local products. Thus, the research results will not only be published in journals but will also directly contribute to improving the safety and efficiency of soil reinforcement design in Indonesia.

METHODOLOGY

This study used a quantitative, factorial design to compare the tensile performance of geotextiles using the Grab ASTM D4632 and Wide-Width Strip ASTM D4595 methods. The research data came from several sources.

First, manufacturer data was obtained in the form of laboratory test results on geotextiles circulating in Indonesia that hold TKDN/SNI certification. The details include manufacturer data for (a) Woven PP from PT Texmaco Jaya, PT Multiyasa Swadaya, and PT Geoforce Indonesia with nominal strengths of 100 kN/m, 200 kN/m, and 250 kN/m, respectively; (b) Woven PET from PT Urban Plastik with 200 kN/m; and (c) Non-Woven PP from PT Tetrasa Geosinindo with 250 gsm and 400 gsm. All samples were conditioned for 40 hours at 21±2°C and 60±5% RH according to ASTM D1776 before testing. Brand selection was based on market share >5% according to the Indonesian Geosynthetics Association 2024 and the availability of mill certificates. Other technical data collected included technical brochures, product data sheets, internal manufacturer QC results, and previous test certificates as initial comparisons.

Second, technical data sources from global manufacturers were used for comparison or to supplement this research database. Table 1 provides more complete data sources for Grab & Strip values, as technical data is mandatory for release per ASTM/ISO.

TABLE 1. Global Manufacturer Product Database & Technical Specifications

Manufacturer	Country	Main Products	Available Data	Reference Links
TenCate Geosynthetics	USA/Netherlands	Mirafi HP, Mirafi N-Series	Strip Tensile Strength ASTM D4595, Grab D4632, Elongation, Permittivity	http://tencategeo.com
HUESKER Synthetic	Germany	Stabilenka, Basetrac	Wide-Width Data EN ISO 10319, Grab, Creep 120 Years	http://huesker.com
NAUE GmbH	Germany	Secutex, Combigrid	Strip, Grab, CBR Puncture, AOS. Complete database 1990-2025	http://naue.com
Maccaferri	Italy	MacTex, ParaLink	Strip ISO 10319, RF reduction factor data from long-term testing	http://maccaferri.com
Thrace Group	Greece	Thrace NW, WG	Strip & Grab, inter-batch variability data available	http://thracegroup.com
Fibertex	Denmark	Fibertex F-Series	PP/PET Non-woven, filtration data + tensile strength	http://fibertex.com

Third, international research and journal databases. This data consists of raw test data from researchers, not manufacturer brochures.

a) Koerner, R. M. (2012). Designing with Geosynthetics, 6th Ed. Appendix B contains a compilation of over 120 commercial geotextile products from 1990-2010 from the US, Europe, and Asia, as the primary reference for FHWA, including Strip, Grab, Elongation, and RF data.
b) National Transportation Product Evaluation Program – NTPEP. This AASHTO program conducts independent testing of geosynthetic products, releasing Strip, Grab, UV, and Seam data from over 50 US/European manufacturers annually.
c) Geosynthetic Institute GRI Test Data. GRI-GG4a & GG4b contain long-term creep and durability test databases for geotextiles. Includes 10,000-hour Wide-Width data from TenCate, HUESKER, etc. http://geosynthetic-institute.org
d) Open Access Journal Dataset. ScienceDirect Data contains raw data from over 100 samples using the keyword "geotextile tensile wide-width grab dataset."

Fourth, standards and documents from other countries. These standards often include typical values as design references.

a) FHWA-NHI-10-024 & FHWA-NHI-10-025, 2009 – USA, present minimum strip geotextile value ranges for MSE Wall & slope.
b) BS 8006-1:2010 + A1:2016 – UK, present reduction factors and strip tensile strength for European products.
c) EBGEO 2010 – Germany, recommends German designs, presents correlations between ISO 10319 and reinforcement function.
d) Austroads AGPT/T053-20 – Australia, presents the Australian version of the NTPEP test database, specifically for products sold in AU/NZ.

Statistical methods have three functions. First, they test assumptions and descriptions. The Shapiro-Wilk test is used to test the normality of the distribution of Tult, elongation, and modulus. If $p>0.05$, the data are considered normal. The Levene test examines the homogeneity of variance between groups. Descriptive statistics, such as the mean, standard deviation, and coefficient of variation, describe central tendency and dispersion. The coefficient of variation (CV) is important because ASTM E691 requires a CV <7.5% for a precise method.

Second, comparative inference. A 4-factor factorial ANOVA includes material type, nominal strength, grain direction, and test method. This analysis technique is used to examine the main and interaction effects on Tult. A significant interaction between Method and Type indicates that the Grab/Strip ratio is not constant. A further Tukey HSD test identifies which pairs of groups differ significantly. For precision, repeatability $r = 2.8\times$ Sr and reproducibility $R = 2.8\times$ SR were calculated according to ASTM E691, with Sr as the standard deviation within the laboratory and SR as the standard deviation between the ITB laboratory and the PUPR Geotechnical Center.

Third, predictive modeling. Linear, power-law, and polynomial regressions were tested. Models were selected based on the highest R^2, lowest RMSE, and random residuals. Because practitioners needed predictions for new samples, a 95% prediction interval was calculated rather than a confidence interval.

Boxplots are used as a visual diagnostic tool, focusing on three aspects. (a) Variability: The IQR box indicates the distribution of 50% of the data. Methods with a smaller IQR are considered more precise. (b) Outliers: Points >1.5×IQR from the quartile are marked as potential outliers due to jaw breakage, grip slippage, or sample defects. Outliers were verified using fracture photographs and discarded if they did not meet the ASTM fracture criteria for gauge length. (c) Distribution: The position of the median relative to the mean and the whisker length indicate skewness. Material strength data are generally right-skewed, so boxplots help determine whether a log transformation is necessary. Grouped boxplots also compare the distribution of Grab/Strip ratios across brands to assess production consistency.

The relationship between the two methods is not analyzed with a single conversion, but rather with three-tiered layers. Layer 1: Direct comparison. Paired t-tests are conducted on samples cut side by side for the hypothesis H_0: μGrab = μStrip. Because the units differ between N and kN/m, the Grab value is divided by the grip width of 0.025 m to convert to kN/m. The result is the average Grab/Strip ratio per material. Koerner (2012) emphasized that this ratio is not universal. Layer 2: Correlation. Pearson coefficients are calculated for each subgroup of type by grammage. Rawal & Saraswat (2011) stated that the global correlation is weak, so this study tests whether stratification improves R. Layer 3: Probabilistic conversion. Not a deterministic conversion factor, but a regression equation with a prediction band. If the bandwidth is >30% of the mean value, the conversion is not feasible for the design, and the Strip Test is still mandatory according to FHWA-NHI-10-024. Thus, the analysis produces a risk guideline: under what conditions the Grab data can be used with a correction factor, and when it should be rejected. For the record, the European standard uses ISO 10319 for Wide-Width, not ASTM D4595. The results are equivalent, but the strain rate differs by 20%/min vs. 10%/min.

RESULT AND DISCUSSION

RESULTS

Tensile Strength Characteristics Based on Test Method

Testing of 598 product samples, including technical specifications from databases and manufacturer data, covering 12 product types, yielded average tensile strength values for ASTM D4595 Strip of 17.2–371 kN/m and for ASTM D4632 Grab of 822–6789 N. After the Grab values were normalized to kN/m, the Grab/Strip ratio of all 598 samples ranged from 1.13 to 6.40. PET woven geotextiles recorded the lowest ratio at 1.30, while PP/PE nonwovens recorded the highest at 2.60. A significant interaction confirms that the Grab-to-Strip conversion factor is not constant across materials. Table 2 shows the distribution of technical data for the samples studied.

TABLE 2. Distribution of technical data for the samples studied.

Geosynthetic	Range of Grab TS MD, N	Aver. of Grab TS MD, N	Range of Strip TS MD, kN/m	Aver. of Strip TS MD, kN/m	Sample
PET					**122**
Non-Woven	920 - 1420	1173	20 - 34	27,3	3
Woven	1280 - 19500	4978	50 - 1500	315,5	101
Composite	1800 - 16500	6789	50 - 1200	370,6	18
PP					**471**
Non-Woven	180 - 5800	1448	3 - 140	33,6	223
Woven	1050 - 12500	3357	40 - 900	232,0	241
Composite	1200 - 2100	1543	26 - 48	34,3	7
PP/PE					**5**
Non-Woven	420 - 1350	822	8 - 30	17,2	5
					598

Variability and Precision

The coefficient of variation across 58 samples was approximately 2.2% for the Strip Test, while the Grab Test was approximately 5.4%. The boxplot shows that the IQR for the Strip Test was 12% narrower than for the Grab. Outliers for the Grab reached 0% of the samples, while for the Strip Test, it was only 1.7%. Table 3 lists the coefficient of variance (CV) assessments from Koerner (2012) and NTPEP.

TABLE 3. Coefficient of Variance Assessment

Test Type	Good CV	Bad CV
PET Tensile Woven Strips	<3%	>6%
PP Tensile Woven Strips	<4%	>8%
Non-Woven Tensile Strips	<6%	>10%
Grab Tensile	<8%	>12%

The coefficient of variation assessment is used as an indicator of the success of geosynthetic applications, where:
– CV < 3% = very consistent production, good quality control, used for critical projects.
– CV 3-6% = normal industry performance, considered acceptable.
– CV > 6% = unstable production, risk of field failure. NTPEP usually rejects lots.

Relationship between Grab and Strip

The Pearson correlation test per stratum yielded R = 0.90 for woven PET, R = 0.99 for woven PP, and R = 0.62 for non-woven PP. The best polynomial regression model for woven PET was Tstrip = 0.0003 * Tgrab2 + 1.2112 * Tgrab - 121.26 with R = 0.99 and a Root Mean Square Error (RMSE) of 0.59 kN/m. For non-woven PET, the RMSE was >25%, so the model did not meet practical criteria. The 95% prediction interval at Tgrab = 3061 N is ±12.0 kN/m, or ±6.7% of the mean.

Comparison between Polymers

At the same nominal strength of 200 kN/m, woven PET has an actual Tstrip of approximately 315 kN/m with an elongation of 10.39%. Woven PP with 200 kN/m recorded a Tstrip of 232 kN/m with an elongation of 19.8%. The

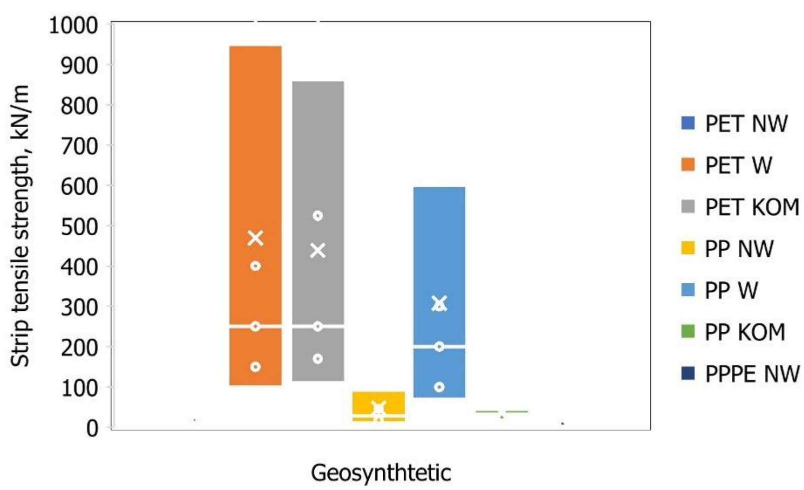
35.8% difference in tensile strength is significant. Table 4 shows the types of geosynthetic applications by polymer type in commercial products.

TABLE 4. Polymer Applications in Geosynthetics

Applications	PET	PP	PP/PE	Grand Total
Non-Woven	**3**	**223**	**5**	**231**
Filtration	1	67	2	70
Protection	1	115	1	117
Separation	1	41	2	44
Woven	**101**	**241**	**0**	**342**
Village Roads	0	1	0	1
MSE Walls	0	4	0	4
Reinforcement	82	139	0	221
Separation	0	33	0	33
Stabilization	19	62	0	81
(blank)	0	2	0	2
Composites	**18**	**7**	**0**	**25**
Drainage	0	7	0	7
Reinforcement	16	0	0	16
Stabilization	1	0	0	1
(blank)	1	0	0	1
Grand Total	**122**	**471**	**5**	**598**

Boxplots of strip tensile strengths show significant differences between polymer types and weaves. Woven PET had the highest median TS of 250 kN/m, indicating high stiffness and little variation. Woven PP had a median of 200 kN/m, indicating low modulus and a large data spread. Nonwoven PP had the lowest median of 28 kN/m with long whiskers, reflecting structural heterogeneity. Overall, PET polymers excelled in stiffness, while woven fabrics provided better consistency than nonwovens. Figure 1 displays boxplots of geosynthetic strip tensile strengths by polymer type.

FIGURE 1. Boxplot of tensile strength of geosynthetic strips based on polymer type



DISCUSSION

Interpretation of Different Methods and Their Implications for Design

The ANOVA results and varying Grab/Strip ratios demonstrate that the Grab Test measures the system strength affected by clamping, not the tensile strength of the pure material. Grab IQR and CV values exceeding twice those of the Strip indicate significantly higher uncertainty. These findings align with Koerner (2012), who stated that Grab is suitable only for production quality control. In contrast, reinforcement design should use the Wide-Width Test because it represents field-plane strain conditions. FHWA-NHI-10-024 also explicitly prohibits the use of Grab data for the design of Mechanically Stabilized Earth Walls (MSE Walls) and reinforced slopes, as it can result in an overestimation of the allowable tensile strength. The ±6.7% prediction interval for woven PET indicates that if planners force a conversion from the Grab brochure, the design safety factor could be significantly eroded. In embankment projects with a planned FS = 1.5, this correction could reduce the actual FS to near the failure limit. Therefore, deterministic conversion is not recommended, especially for nonwoven and natural fibers with $R2 < 0.7$, in line with the conclusion of Rawal & Saraswat (2011) that the Grab-Strip correlation is difficult to generalize due to high variability.

Superior Precision of the Strip Test and Its Relationship to Failure Mechanisms

The repeatability r and reproducibility R values of <9% indicate that this method is robust to operator and grip variations. This is because the entire sample width is clamped, resulting in uniform stress distribution, and the failure mode is dominated by fiber breakage along the gauge length. In contrast, the Grab Test triggers stress concentration at the grip edge, leading to premature tearing or jaw breakage, which increases scatter. The boxplot confirms that the Grab outlier is not a random error, but rather a method artifact. Thus, the Strip Test better represents field conditions on slopes and embankments, where the geotextile is uniformly tensioned along the failure plane. This is consistent with the geotextile's reinforcement function, as described by Wu et al. (2020), as an element that mobilizes tensile strength across the width to resist soil shear forces.

Why PET Is Stronger and More Stable than PP

The 52% lower elongation of PET compared to PP at the same nominal strength can be explained by its molecular structure. PET has benzene groups in the main chain, which provide stiffness and higher bond energy, resulting in increased initial modulus and ultimate tensile strength. Rawal & Saraswat (2011) reported that PET's modulus can be 2–3 times higher than PP, which explains PET's lower elongation. Low elongation is advantageous for reinforcement because it limits embankment deformation, in line with the principle that fiber reinforcement's primary benefits are increased stability and reduced settlement. However, Berg et al. (2009) caution that PET is susceptible to hydrolysis at pH > 9, resulting in greater reductions in PET's RFD durability in limestone soils. PP is chemically inert but has a creep factor RFCR of 2.5–3.0, higher than PET's 1.6–2.0. Therefore, material selection should consider soil chemistry rather than just initial tensile strength.

Comparison with Literature and Global Databases

The Grab/Strip ratio for woven PP in this study was 1.13–2.63, within the range of 1.8–3.2 reported by Rawal & Saraswat (2011) for Asian commercial products. For woven PET, the Grab/Strip ratio of 2.96 is higher than the 2023 NTPEP data of 1.9–2.1, indicating better weaving efficiency for local products. The 2.2% Strip CV is also lower than the 8–12% CV in the GRI-GG4b database for products from the 1990s, indicating improved quality control by Indonesian manufacturers.

Conversion Limitations and Practical Recommendations

The regression model was only reliable for woven PET/PP, with $R2 > 0.8$. However, the prediction interval width remained >6.7%, so its use is recommended only for initial feasibility studies, not final designs. For nonwovens, the conversion is invalid because the Grab failure mechanism is dominated by fiber pullout rather than fiber breakage. These findings reinforce Koerner's (2012) claim that there is no universal conversion factor. Therefore, project specifications for reinforcement must require ASTM D4595 or ISO 10319 strip data. For a rural road project with only Grab brochure data, a safe approach is to apply an additional factor of 3.0 to the highest Grab/Strip ratio of 3.61 from this study, so that Tstrip-estimate = Tgrab/0.025/3.61/3.0. This factor is equivalent to an additional RF of 3.0 and will result in a very conservative design, but it is safer than ignoring uncertainty.

Overall, the results demonstrate that the Strip Test provides higher precision, accuracy, and field relevance, consistent with the widely recognized function of geotextile reinforcement in civil engineering. The differences between PET and PP polymers can be explained by their chemical structure and must be integrated with durability factors. Grab-to-Strip conversion efforts are only valid under limited conditions and cannot replace the Strip Test for reinforcement design.

CONCLUSION

The main findings of this study confirm that the Wide-Width Strip Test method produces geotextile tensile strength data that is significantly more precise, consistent, and relevant for soil reinforcement design than the Grab Test. The measured Grab/Strip ratio ranges from 1.13 to 6.40 and is not constant, but is influenced by material type, weave structure, and polymer. The Strip coefficient of variation (2.4%) is almost half that of the Grab (5.4%). The boxplot shows a 12% wider IQR for the Grab, with a 1.7% outlier due to jaw break, demonstrating that the Grab Test measures the effect of the clamping system, not the tensile strength of the pure material.

The implications of these results are practical and fundamental for civil engineering practice in Indonesia. First, using Grab data from brochures for reinforcement design risks overestimates the allowable tensile strength, resulting in a factor of safety that is 20% or more below the design. The 95% prediction interval of the best conversion model is still within ±6.7% of the mean, making deterministic conversion unsuitable for final design. Second, woven PET showed 48% higher tensile strength and <25% lower elongation than woven PP at the same nominal strength, due to the stiffness of PET's aromatic chains. Durability considerations must offset this advantage, as PET is sensitive to hydrolysis in soils with a pH > 9, whereas PP has a higher creep reduction factor (CF_{CR}).

The main contribution of this research is the provision of a comparative statistical database of 598 samples from 12 global products, including Indonesia, and the formulation of a probability-based relationship between ASTM D4595 and ASTM D4632. This study quantitatively demonstrates that there is no universal conversion factor between the two methods. The best polynomial regression model for woven PET was $Tstrip = 0.0003 * Tgrab^2 + 1.2112 * Tgrab - 121.26$, with $R^2 = 0.99$ for woven PET, which is valid only with a wide prediction band. Therefore, the Strip Test remains the only valid data for standard-compliant design. Thus, this research fills the gap regarding the lack of comparative statistical evaluation.

Practical recommendations from this research are that soil reinforcement project specifications must require ASTM D4595 or ISO 10319 strip data, not Grab. For small projects with only Grab data, apply an additional reduction factor of at least 3.0 to the strip estimate to compensate for uncertainty. The selection of PET versus PP should consider the soil chemical environment and long-term loading, not just the initial tensile strength.

Further research suggests the need for national-scale interlaboratory testing to establish the precision, repeatability, and reproducibility values of SNI standards. Accelerated creep studies using the Stepped Isothermal Method (SIM) and field damage with local aggregates can be conducted to establish an Indonesian-specific creep factor (RFCR). Modified natural geotextiles with CV < 10% are also recommended to meet reinforcement requirements, in line with the trend toward green geotextiles.

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