TO TEAR OR NOT TO TEAR

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Abstract

Tear strength is one of the mechanical properties that determine whether a nonwoven can be used as a carrier in a waterproof bituminous roofing membrane. Damage done by storms to roofs involves some tearing failure of the roofing membranes as well as tearing-out of mechanical fasteners.

Since tearing is such an important phenomenon various nonwovens and tear test methods have been investigated. A possible explanation of the differences in tearing behaviour between different materials is presented. Also, the consequences of these differences with regard to the mechanical behaviour of the roofing membrane are discussed. The large variety of bituminous compounds and the variability of many of those compounds make it difficult to evaluate the effect on tearing behaviour. Various tear test methods have been used in this investigation, including the trapezoid, single rip and tongue tear tests. As mechanical fastening of roofing membranes is becoming increasingly important, the nail tear-out test has also been included.

Keywords: tearstrength, tear test, nonwoven, paper, waterproof bituminous roofing membrane

Premessa

La resistenza alla lacerazione, è una delle propietà meccaniche che determinano la possibilità di impiego di un non-tessuto quale rinforzo di membrane per impermeabilizzazione. Forti venti possono sovente causare danni legati alla lacerazione del manto od al cedimento dei punti di ancoraggio. Visto l'importanza di tale parametro, si è voluto analizzare vari non-tessuti ed I metodi di prova.

Viene qui', presentata un'analisi del differente comportamento alla forza di lacerazione di diversi materiali ed una valutazione delle consequenze che tali varie risposte possono avere sulla "performance"fisico-meccanica del manto di copertura.

Il grande numero di mescole bituminose e la loro variabilità, ha reso difficoltoso definire l'influenza sui comportamenti alla lacerazione. Diversi metodi di prova sono stati adottati per questo studio, inclusi quelli a trapezio, a singolo e doppio taglio "avviato". Dato la crescente importanza del fissaggio meccanico, si è voluto verificare anche I valori di resistenza al chiodo.

Zusammenfassung

Die Weiterreissfestigkeit ist eine der mechanischen Eigenschaften die bestimmen, ob ein Vlies als Träger in den Dachbahnen eingesetzt werden kann. Beschädigungen der Dächer durch Stürme sind oftmals ein Resultat von ungenügender Reissfestigkeit der Dachbahnen wodurch die Bahnen aus der mechanischen Befestigung reissen.

Aufgrund der wichtigen Eigenschaft "Reissfestigkeit", wurden verschiedene Vliese und Testmethoden untersucht. Eine mögliche Erklärung für dass unterschiedliche Reissverhalten zwischen verschiedenen Materialien wird dagelegt sowohl als Diskussion der Konsequenzen Unterschieden hinsichtlich des mechanische Verhalten der Dachbahn.

Die große Anzahl der bituminösen Mischungen und die Unterschiede der Compounds erschweren die Beurteilung der Effekte auf die Weiterreissfestigkeit der Endprodukte. In dieser Untersuchung wurden verschiedene Tests zur Bestimmung der Weiterreisskraft durchgeführt, sowie der Schenkel- und Zungen Weiterreissfestigkeit und der Trapeztest. Da die mechanische Befestigung der Dachbahnen stets mehr praktiziert wird, wurde der Nagel-Ausreisstest ebenfalls in die Versuchsreihe einbezogen.

Résumé

La résistance à la déchirure est une des propriétés mécaniques, qui détermine si un nontissé peut être utilisé comme armature dans une membrane d'étanchéité.

Le dommage causé aux toitures, pas les orages, implique quelquefois une déchirure de la membrane, ainsi qu'un arrachement des attaches mécaniques. Parce que la déchirure est une phénomène tellement important, différents nontissés et différentes méthodes d'essais ont été étudiées. Une explication possible des différences dans le comportement à la déchirure entre les matériaux est présentée, ainsi qu'une discussion sur les conséquences qu'ont ces différences sur le comportement mécanique de la membrane d'étanchéité.

La grande variété des composés et la variabilité de beaucoup d'entre eux rend difficile l'évaluation de l'effet du comportement à la déchirure.

Des méthodes de tests variées ont été utilisées pour cette investigation, comme celle du trapézoïde ou déchirure amorcée. Considérant l'augmentation importante des systèmes mécaniques de fixation, le test de la déchirure au clou a été aussi inclus.

1. Introduction

Tear strength is one of the mechanical properties that roofers and roofing membrane manufacturers look at to determine whether a nonwoven can be used as a carrier in a roofing membrane.

Damage to roofs caused by storms may involve some tearing failures of the roofing membranes as well as tearing-out of mechanical fasteners.

While tearing is a familiar phenomenon, few efforts appear to have been made to fully understand it. Yet, since it is such an important property, tearing should be thoroughly understood by nonwoven producers and roofing membrane manufacturers.

This paper addresses the behaviour of nonwovens in tear tests and also presents a few comparative results of different types of tear tests.

For a nonwoven to perform well, in a tear test, the filaments have to be strong and relatively mobile, i.e. they have to be able to re-orient and to straighten out.

A staple fibre nonwoven tends to tear like paper. In a filament nonwoven, however, particularly a bi-component filament nonwoven, a tear test does not cause the nonwoven to be **torn** apart but to be **pulled** apart.

For such a nonwoven a trapezoid test becomes a **tensile test**. The nonwoven, being the carrier, is one of the two components that make up a waterproof bituminous roofing membrane, with the second component being the bituminous compound.

The mechanical behaviour of a roofing membrane appears to be mostly determined by the carrier, but the bituminous compound also contributes to the mechanical properties. The extent of this contribution, however, has been found to be difficult to assess. The reason being the large variety of bituminous compounds and the variability of many of those compounds.

Based on the results of many tests done in the past on all sorts of membranes a couple of observations can be made:-

First, the addition of bitumen seems to increase the nail tear-out strength.

Second, the trapezoid test results often indicate a decrease in strength due to the addition of a bituminous compound.

2. Tear tests

In order to quantify tear strength several types of tests have been developed and are specified in standard test methods, like ASTM, DIN, EDANA, ISO, and EN.

The most common tests are (see Figure 1):

Single rip test	DIN 53.859 Teil 2,
Tongue test	DIN 53.859 Teil 1
Butterfly test	ASTM D 624
Trapezoid test	DIN53.363,
Nail test	DIN 53.506

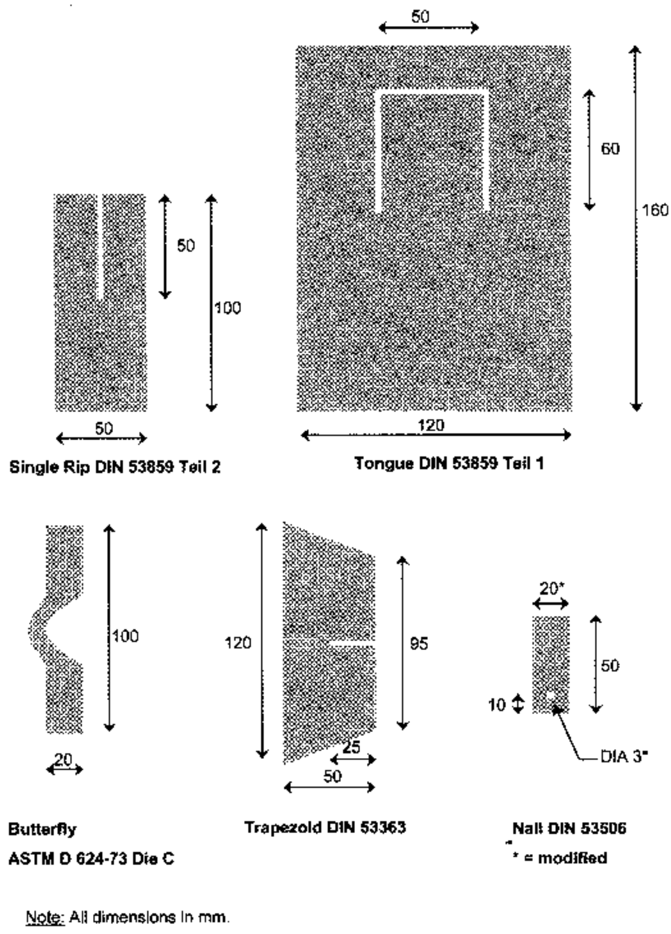
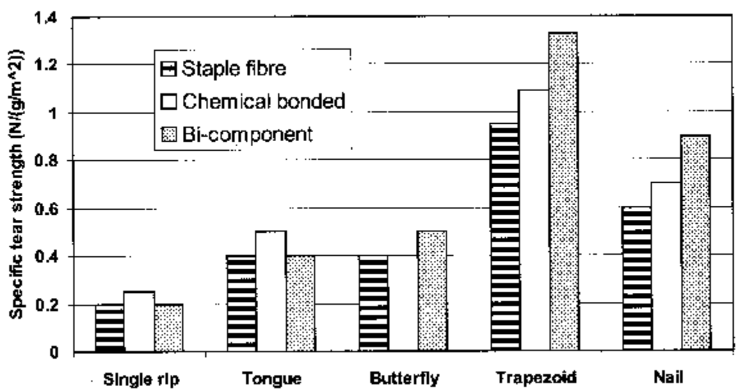


Figure 1: Commonly used tear test specimens.

The single rip and tongue tear tests simulate the way one would tear up a piece of paper or nonwoven. As they are among the most commonly used tests they have been employed in this study.

For this study it was important to record the tearing process as close as possible to the tip of the tear using a video camera. Since this turned out to be a problem with the single rip and tongue tear tests, the trapezoid test was also frequently employed.

Figure 2 shows test values obtained using all five tests on Staple fibre nonwoven, Chemical bonded filament nonwoven and Thermal bonded bi-component filament nonwoven.



nonwovens obtained from 5 different types of tests.

3. Tearing behaviour

Tearing is a familiar type of failure. A piece of paper, for instance, can be torn from the top of the sheet to the bottom and from the left side to the right side. When slowly tearing a piece of paper, like standard copier paper, one will feel that the tearing force increases and decreases and increases again, and so on.
A typical force-displacement graph generated during a tear test in a testing machine looks like the one shown in **Figure 3**.

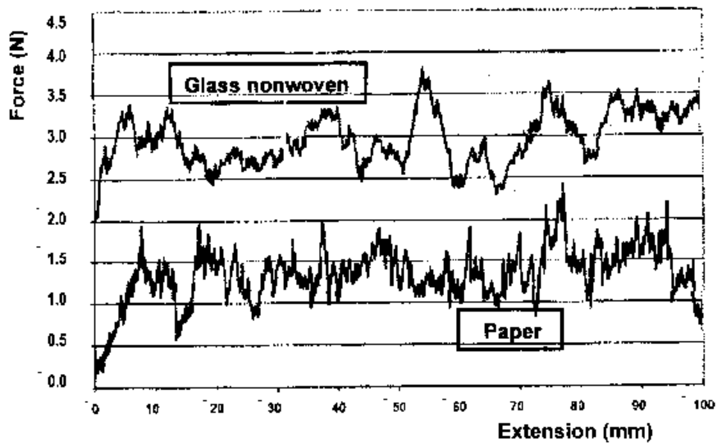


Figure 3: Tongue tear test force-extension curves of paper and glass nonwoven.

The saw-tooth shape of the graph can be explained as follows:

The strength of paper and nonwovens depends on the strength of the **bond points** and the **strength** of the **fibres or filaments**.

A single bond point is much weaker than a fibre or a filament. If the fibres or filaments are bonded by a relatively small number of bond points, tearing of the nonwoven would be caused primarily by breaking bond points. When there are relatively many bond points, failure of the nonwoven would be caused by breaking fibres.

Paper can be viewed as a fibre nonwoven in which the fibres are bonded by a large number of bond points. As the tearing force is increased a fibre will break causing the load to decrease and the tear to propagate to the next fibre or fibre bundle. The tear will stop at this fibre and the load will increase until this fibre breaks and the tear propagates to the next fibre.

Fibres that locally are (nearly) perpendicular to the tear will cause the tear to stop and the load to increase. As not all the fibres in the path of the tear are perpendicular to it, the tear will propagate some distance (from a few tenths of a mm to perhaps one mm) before it reaches a perpendicular fibre or fibre bundle. In the graph this corresponds with the displacement between a top and the next "bottom".

As shown in **Figure 3** glass staple fibre nonwoven behaves like paper as it is composed of chemical bonded short fibres (i.e. relatively many bond points).

In a filament nonwoven the number of bond points is relatively small and hence, in a tear test, failure of the nonwoven would primarily be caused by breaking bond points.

As the bond points break, however, the filaments are free to shift and to re-orient to better carry the load. If the filaments are sufficiently strong they will remain intact and continue to re-orient and straighten out as bond points continue to break.

As a result, the tear will not be able to propagate and the filament nonwoven will **not be torn apart but will be pulled apart**, which in general requires a much greater force. **Figure 4** represents the force-displacement curves of tongue tear tests of a chemical bonded nonwoven and a thermal bonded bi-component filament nonwoven.

The tearing behaviour of the chemical bonded nonwoven lies somewhere between the behaviour of paper and the behaviour of the bi-component filament nonwoven.

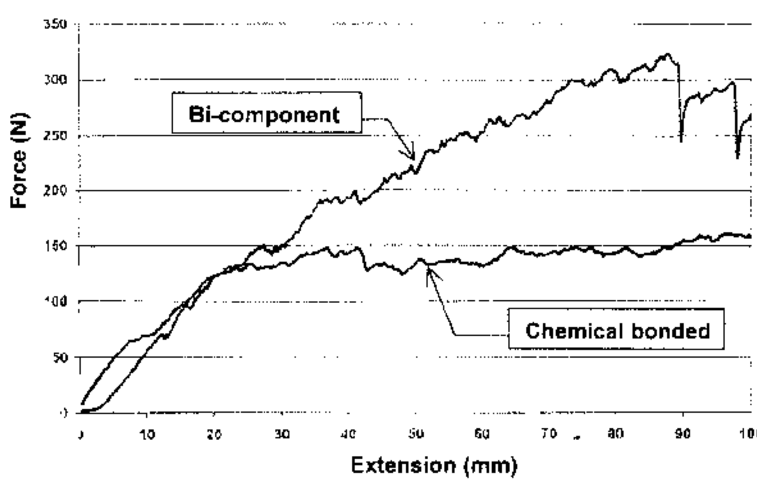


Figure 4: Tongue tear test force-extension curves of chemical bonded and bi-component nonwovens.

Filament strength is related to the area of the filament cross section, i.e. to the diameter squared.

If filament A is twice as thick as filament B, then the strength of filament A is approximately four times the strength of filament B. So, the thickness of the filaments will also affect tearing behaviour and tear strength.

Typical fibre and filament diameters are:

Paper	5-10μ	(1μ= 0.001 mm)
Glass	11μ	
Staple fibre	19μ	
Endless filaments	20μ	
Endless bico filaments	38μ	

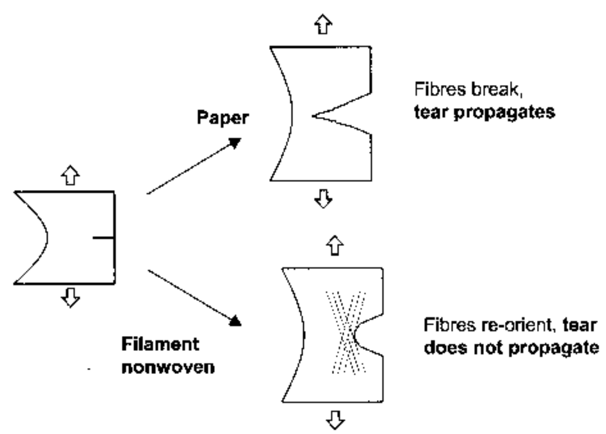


Figure 5: Behaviour of paper and filament nonwoven in a trapezoid tear test.

In **Figure 5** the tearing behaviour of paper and filament nonwoven are schematically represented and **Figure 5A** shows a few pictures taken during trapezoid tear tests.

Since in the filament nonwoven most filaments are re-oriented instead of broken, the tear test becomes a tensile test and the so-called **tear strength is actually a tensile strength.**

While staple fibre nonwovens behave like paper, the behaviour of a chemical bonded filament nonwoven lies somewhere in between the behaviour of paper and the behaviour of bi-component filament nonwoven.

In a tear test a bi-component filament nonwoven is stronger than other types of nonwoven because it does not tear; its re-orienting filaments form crack-stopping bundles.
Conversely, in paper or staple fibre nonwovens the fibers cannot act as crack-stoppers since they break rather than re-orient.
Hence, the mobility of the filaments is a key factor in the superior performance of the bi-component filament nonwoven in a tear test.

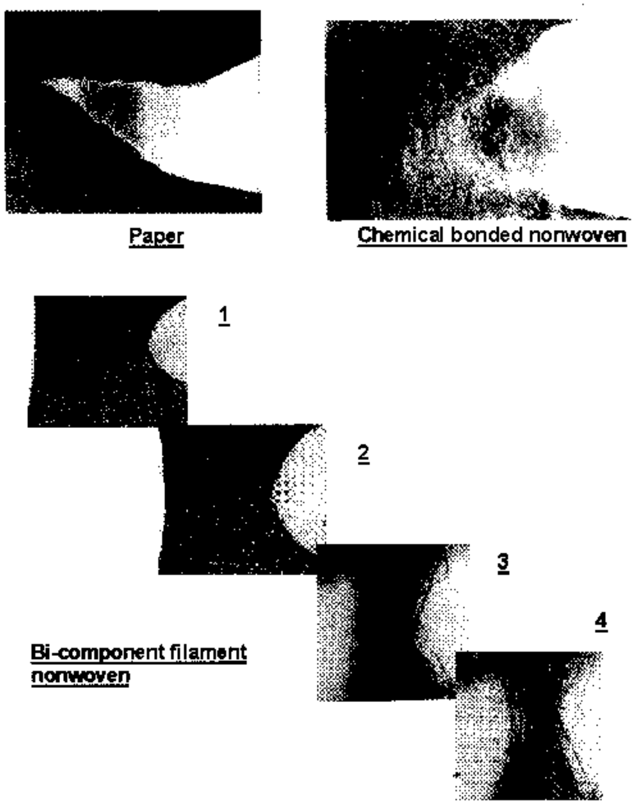


Figure 5A: **Tearing behaviour of paper, chemical bonded nonwoven and bi-component filament nonwoven.**

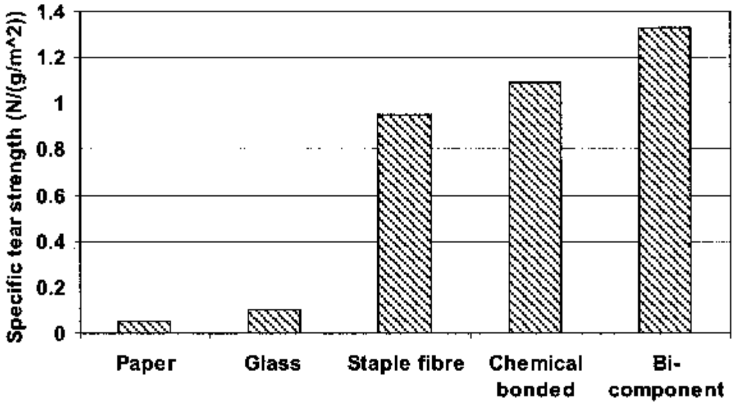


Figure 6: Specific tear strength of paper and various nonwovens.

Figure 6 shows the specific tear strength of different tested nonwovens

For the tests the following materials were used:

- Paper
- Glass fibre nonwoven
- Staple fibre nonwoven
- Chemical bonded filament nonwoven
- Thermal bonded bi-component nonwoven

The nail tear-out test closely simulates the situation where the roofing membrane is attached mechanically to the roof structure. It differs from the other tear tests because around the nail there are two potential failure modes: pull-through and tear out.

A one-to-one relationship between the nail test and the other tear tests may, therefore, not exist.

Hence, the nail tear-out test should always be done in addition to one or more of the other tear tests, because the relationship with the practice.

4. Effect of bitumen on tear strength

One of the two components that make up a waterproof bituminous roofing membrane, being the carrier, with the second component being the bituminous compound.

The mechanical behaviour of a roofing membrane appears to be mostly determined by the carrier, but the bituminous compound also contributes to the mechanical properties. The extent of this contribution, however, has been found to be difficult to assess. The reason being the large variety of bituminous compounds and the variability of many of those compounds.

Based on the results of many tests done in the past on all sorts of membranes a couple of observations can be made:-

First, the addition of bitumen seems to increase the nail tear-out strength.

Second, the trapezoid test results often indicate a decrease in strength due to the addition of a bituminous compound.

5. Conclusions

1. Filament nonwovens, and bi-component filament nonwovens in particular, show much higher strengths in tear tests than staple fibre nonwovens because of the mobility and the strength of the filaments.

   In a tear test such nonwovens are not torn apart but pulled apart; the tear test has actually become a tensile test.

   Arranging various nonwovens in order of increasing strength:

   Paper → Glass short fibre →

   PET Staple fibre → PET Chemical Bonded → PET Bi-Component.

2. Increasing the strength in a tear test can be accomplished by:
   - increasing the filament **diameter**

- increasing the **mobility** of the filaments
- using **endless filaments** instead of short (staple) fibres

3. The nail tear-out test closely simulates the way mechanical fasteners apply force to the nonwoven or roofing membrane and should, therefore, be included in every tear test program.

4. The effect of the bitumen on the mechanical behaviour of a waterproof bituminous roofing membrane is difficult to assess because of the large variety of bituminous compounds and the variability of many of those compounds.

The addition of bitumen seems to increase the nail tear-out strength but in the trapezoid test often results in a decrease in strength.

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