WHO Prequalification of Vector Control Products

Phys/Chem tests for ITNs: Hole enlargement resistance

Factors which may affect validity of tests and results using the **hole enlargement resistance method**

- incorrect measurement of Feret's diameter;
- incorrect positioning / cutting of the wound on warp knitted ITN fabrics;
- incorrect observation of secondary failure (laddering, unravelling or tearing/tearing combined with laddering or unravelling);
- application of incorrect testing parameters for hole enlargement resistance testing of ITNs;
- not using 1.5 mm thick diaphragm (1.5 mm thick diaphragm should be used);
- not checking regularly whether the diaphragm is damaged. This should be regularly checked;
- incorrect location of the test sample. The test sample should be centrally located above the diaphragm.

1. Purpose of the Method

This document describes the method for assessing the hole enlargement resistance in open mesh textile structures such as those used in Insecticide-treated nets (ITNs). Holes enlarge during use as a result of yarn breakage and tension applied to the fabric. This method assesses the extent to which hole enlargement is resisted.

2. Considerations for Use of the Method

The test sample is first wounded by cutting yarns to create a hole and cyclic pressure is applied on the wounded sample to measure the resistance to hole enlargement. After wounding the sample, the sample is mounted on a pneumatic bursting strength tester, with a 50 cm^2 circular test area, ensuring that the preformed hole is centrally located above the diaphragm below. The sample is then exposed to 3 consecutive cycles of loading by partial inflation of the diaphragm, which tensions the sample according to a set pressure but does not result in yarn breakage. The hole size after tensioning is assessed, as are any secondary failures that occur as a result of the loading, such as laddering, tearing and unravelling.

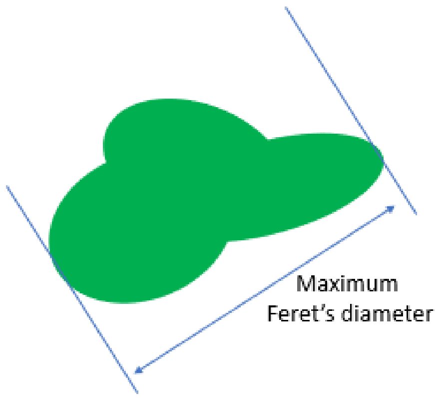
WHO Prequalification of Vector Control Products
Avenue Appia 20
1211 Geneva 27, Switzerland

For further information, contact:
pqvectorcontrol@who.int
https://extranet.who.int/prequal/vector-control-products

2.1. Terminology

- **Open mesh textile**: A textile which due to its inherent structure consists of a large number of closely spaced apertures.
- **Aperture**: An opening in the textile structure larger than 1 mm.
- **Hole**: An opening in a textile which is not part of its inherent structure and is the result of breakage or displacement of yarns.
- **Hole enlargement**: The enlarging of an existing hole in a textile structure as a result of tension applied to the fabric.
- **Maximum Feret Diameter**: The largest diameter defined as the distance between two parallel lines at the extremities of the object that are tangential to the boundary. An example is given in Figure 1.

Figure 1. Maximum Feret's diameter *(1)*.



- **Secondary failure**: Laddering, tearing and unravelling are mechanisms of hole enlargement assessed by visual inspection of the sample after testing is performed.
- **Laddering**: A ladder or laddering is caused by sequential loop disengagement in a knitted structure. Laddering presents itself as sequential un-looped but unbroken yarns which run parallel throughout the knit structure and it does not form a hole by itself.
- **Unravelling**: Unravelling is caused by sequential loop disengagement in a knitted structure. In unravelling the loops of a knitted structure disengage to create a hole.
- **Tear**: Tear is the tensile breakage of yarns in one or more directions. Tears are usually associated with large hole sizes (> 21 mm).

3. Apparatus and Materials

3.1. Apparatus

- A pneumatic bursting strength tester is required capable of cyclic loading according to the parameters given in Table 1.
- The bursting strength tester should be fitted with a 1.5 mm thick diaphragm.

3.1.1. Additional items of equipment required are:

- Piece glass or magnifying glass.
- Ruler capable of measuring to 1 mm.

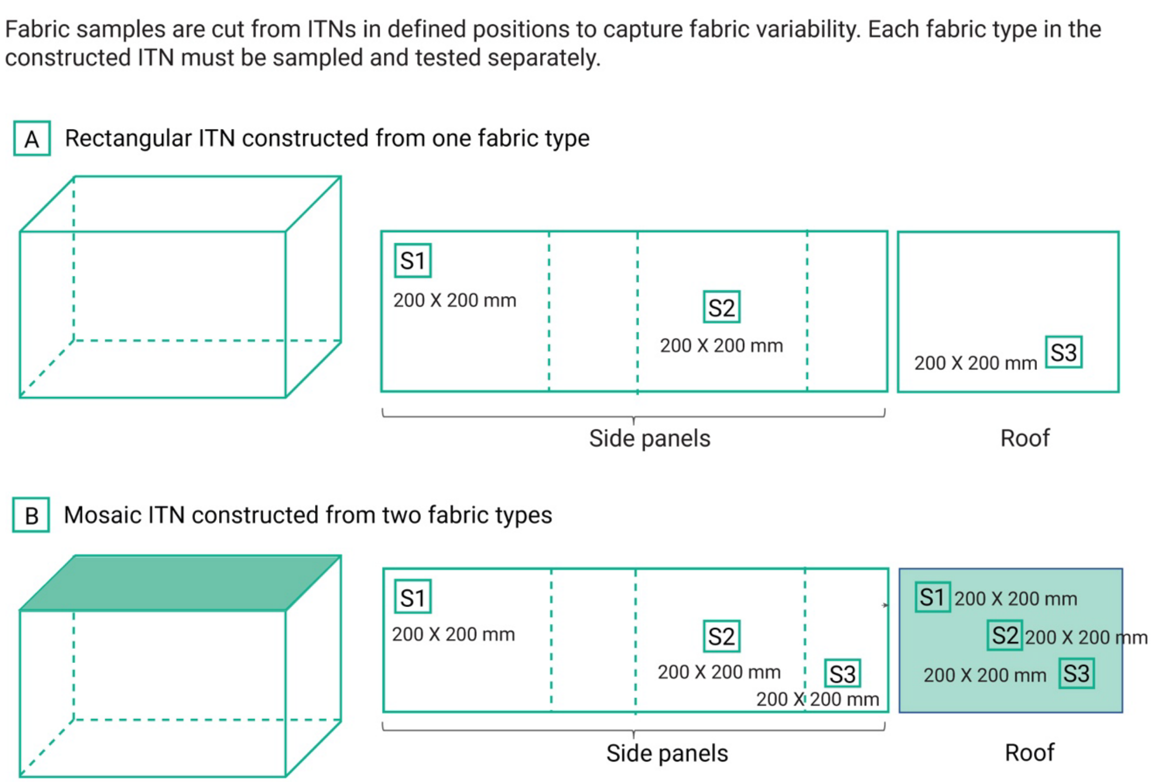
4. Sampling and Test Samples

4.1. Sampling

Sampling procedure for ITNs is dependent on the design and construction of the ITN, including the presence of multiple fabrics in the ITN design. The sampling procedure is declared in the Implementation guidance: Declaration of ITN construction and sampling and must ensure that any differing fabrics in the ITN are adequately represented. The total number of samples required is dependent upon the study and the product.

For the data generation for PQ Module 3 dossier on hole enlargement resistance of ITNs, four ITNs per batch and three samples per fabric type per ITN are required for testing. Figure 2 shows an example of ITN sampling schemes. The position of samples should be measured from the left hand and top seams of each panel.

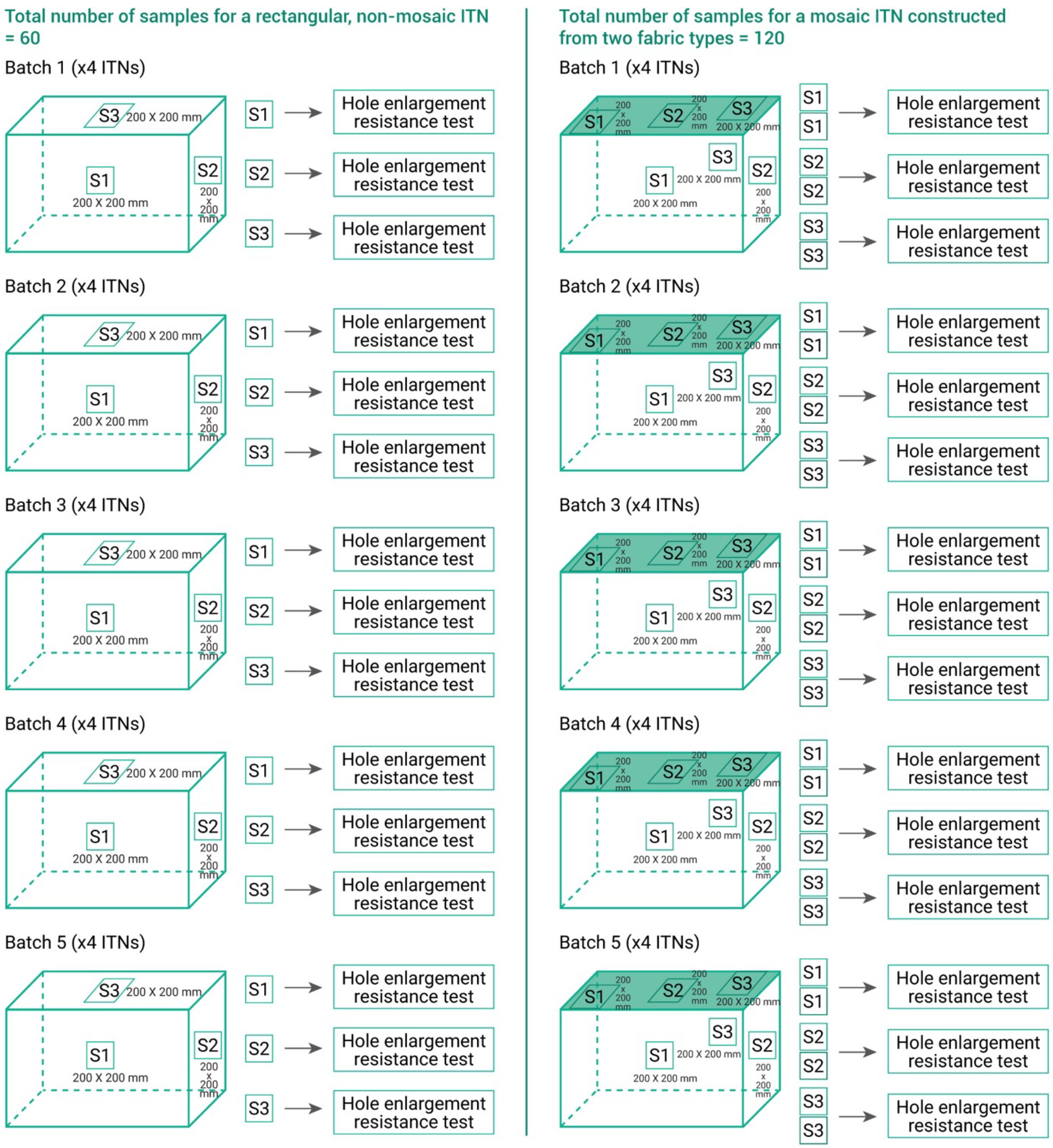
Figure 2. Example ITN sampling schemes for hole enlargement resistance of insecticide-treated nets.



Therefore, a total of 60 (3 samples per ITN x 4 ITNs per batch x 5 batches) samples are required for the measurements of homogeneous nets. For mosaic ITNs consisting of two fabric types, a total of 120 samples (3 samples per ITN x 4 ITNs per batch x 5 batches x 2 fabric types) are required.

When taking the samples for testing it is important to ensure that they do not share wale yarns.

Figure 3. Example of total number of samples required for hole enlargement resistance of insecticide-treated nets.



4.2. Test Samples

The fabric test area is a circular sample of at least 140 mm in diameter. Typically, a square of 200 X 200 mm is utilized for testing.

5. Conditioning

The atmospheres for preconditioning, conditioning and testing are as specified in ISO 139:2005 *(2)*.

6. Procedure

6.1. Test programme parameters - ITN hole enlargement resistance testing

The test parameters for ITNs testing are outlined in Table 1.

Table 1. Testing parameters for hole enlargement resistance testing of ITNs.

Bursting test area	50 cm2
Target Pressure	80 kPa
Inflation rate	15 kPa/s
Number of cycles	3
Time held at target pressure	3 seconds
Relax time between cycles	3 seconds
Auto correction of inflation rate	off

6.2. Preparing samples - Wounding of ITN samples

To prepare a warp knitted ITN sample, one complete unit cell of mesh is cut out and removed. Examples are given in Figures 4 *(3)* and 5 *(4)* for two warp knitted fabrics with different knitted structures (A and B). The red dashed lines indicate the cut lines required to remove the mesh section.

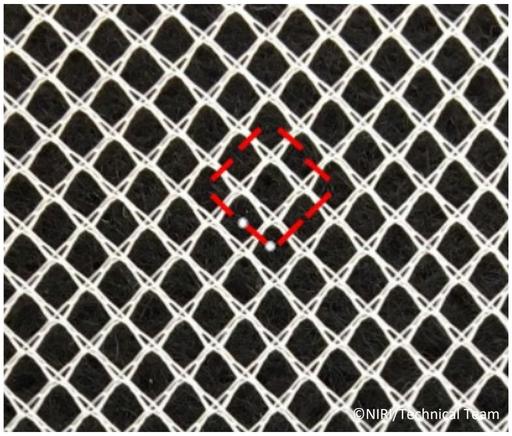


Figure 4.
Example of wound position on warp knitted ITN fabric structure A.

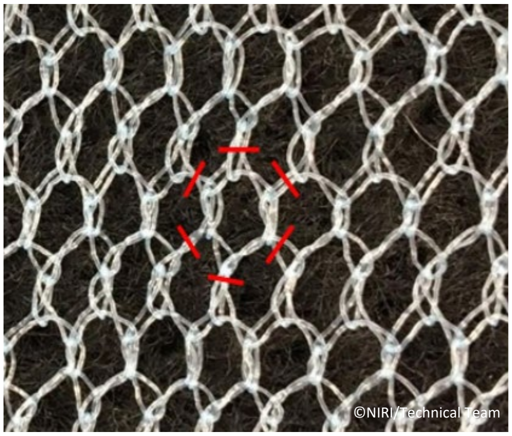


Figure 5.
Example of wound position on warp knitted ITN fabric structure B.

6.3. Test Procedure

1. Mark the center of the sample.
2. Cut the center of the sample as shown in Figures 4 and 5 to remove a mesh section, creating a hole.
3. Place the sample on the bursting strength tester ensuring that the hole area is positioned immediately above the center of the diaphragm.
4. Clamp the sample.
5. Commence inflation and deflation of the diaphragm (see Table 1).
6. Measure the end hole size in mm after testing, according to the maximum Feret's diameter.
7. Record the presence of any secondary failure (laddering, tearing, or unravelling).

6.4. Recording Results

6.4.1. Measuring the end hole size

The end hole size is measured according to the maximum Feret's diameter. Examples of how to measure are given in Figures 6a *(5)* and 6b *(6)*.

Optical microscopy and image analysis may be employed to aid measurement of the end hole size, as well as to identify secondary failure (if required)

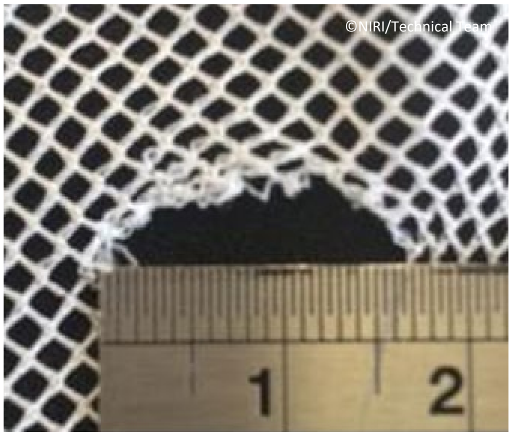


Figure 6a. Example of measuring the wounded area after testing (the end hole size) in structure A. In this example the end hole measures 17 mm.

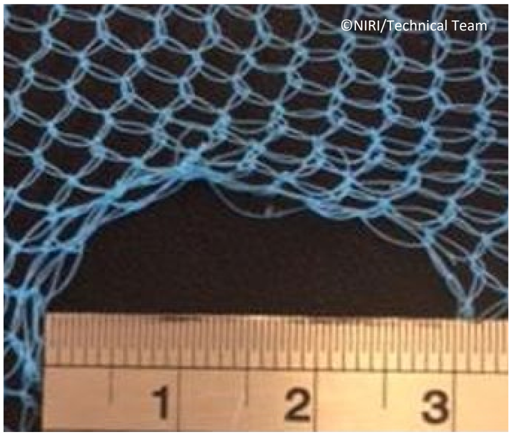


Figure 6b. Example of measuring the wounded area after testing (the end hole size) in structure B. In this example the end hole measures 30 mm

6.4.2. Assessment of secondary failure

In addition to the end hole size, record if the sample shows any secondary failure. It should be noted that a hole in which secondary failure has occurred is likely to be elliptical or oblong in shape rather than circular.

There are three types of secondary failure as shown below:

1. Laddering.
2. Unravelling.
3. Tearing, tearing combined with laddering or unravelling.

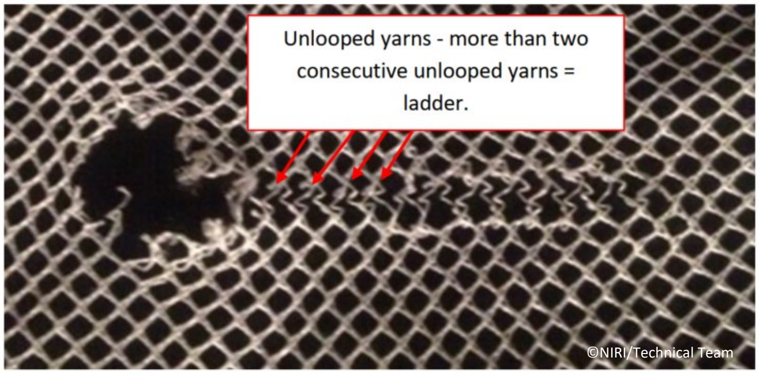
6.4.2.1. Identification of laddering

Laddering presents itself as sequential unlooped but unbroken yarns that run parallel in the knitted structure. The ladder itself does not form a hole.

In laddering two or more consecutive 'ladder rungs' must be visible in the structure. A ladder rung consists of unlooped yarns, but do not form a hole.

Figure 7 *(7)* shows an example of laddering.

Figure 7. Structure A. Example of laddering. Multiple unlooped yarns are visible - two or more unlooped yarns associated with a ladder.



6.4.2.2. Identification of unravelling

In unravelling, the loops of the yarns sequentially disengage leading to a larger hole. This is characterized by open loops at the perimeter of the hole. Examples of unravelling are shown in Figures 8 *(8)* and 9 *(9)*.

In unravelling, two or more consecutive unlooped yarns occur.

Figure 8. Structure B. Example of unravelling. Two empty loops are visible caused by unravelling.

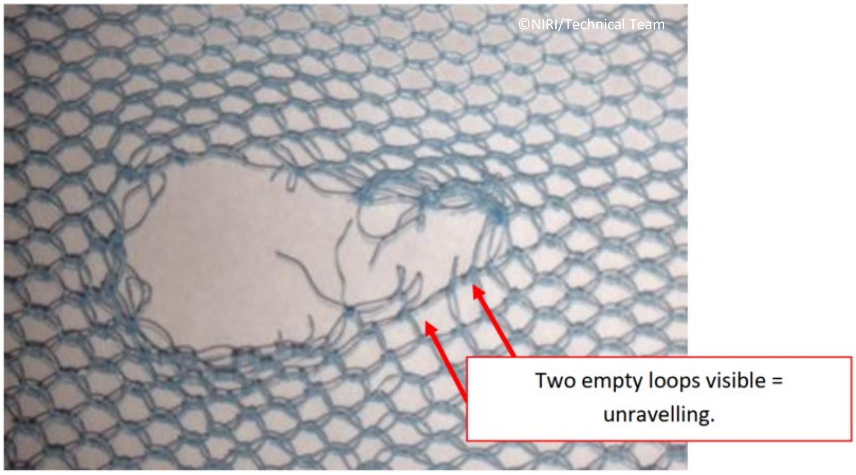
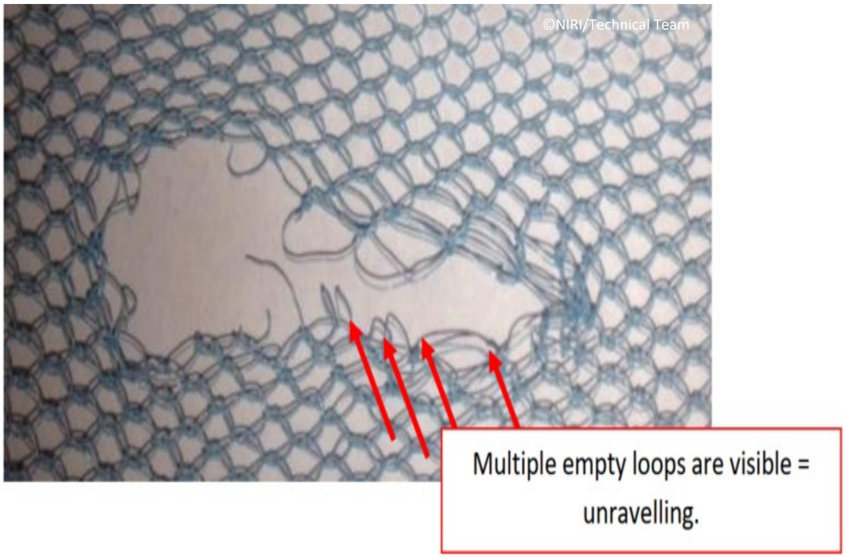


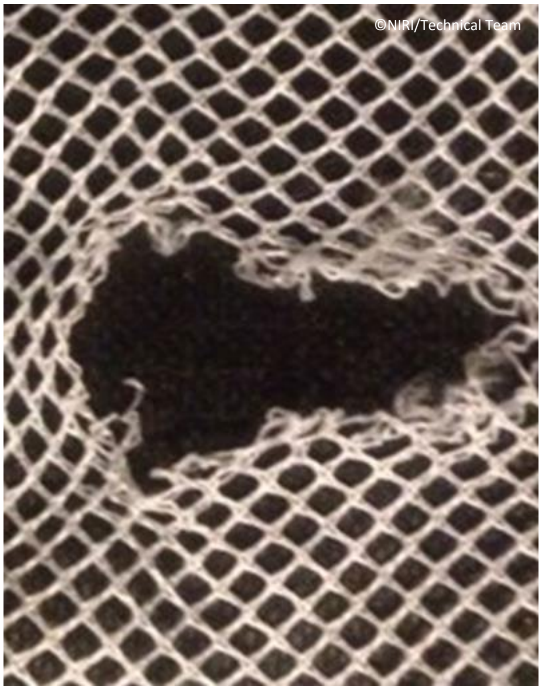
Figure 9. Structure B. Further example of unravelling. Multiple empty loops are visible.



6.4.2.3. Identification of tearing

Tearing is where one or more of the unlooped yarns associated with the ladder has broken as shown in Figure 10 *(10)*. The broken yarns create a hole. In tearing, two or more 'ladder rungs' are broken. Tearing is typically associated with a large end hole size of > 21mm.

Figure 10. Structure A. Example of a tearing (broken rungs).



6.5. Hole Enlargement Resistance Scoring

The hole enlargement resistance score is based on:

1. the average end hole size and,
2. the presence (or not) of secondary damage in the form of laddering, unravelling, or tearing, as defined in Table 2.

The hole enlargement resistance score is determined by reference to Table 2. First, identify which of the three end hole size categories in Table 2 correspond to the measured end hole size obtained in testing (<5 mm, 6-20 mm or >21 mm).

If there is no secondary damage, then report the hole enlargement resistance score shown on the line labelled 'none' (Table 2). If secondary damage is present, then report the hole enlargement resistance score corresponding to that type of damage shown in Table 2 (laddering, unravelling or tearing/tearing combined with laddering or unravelling).

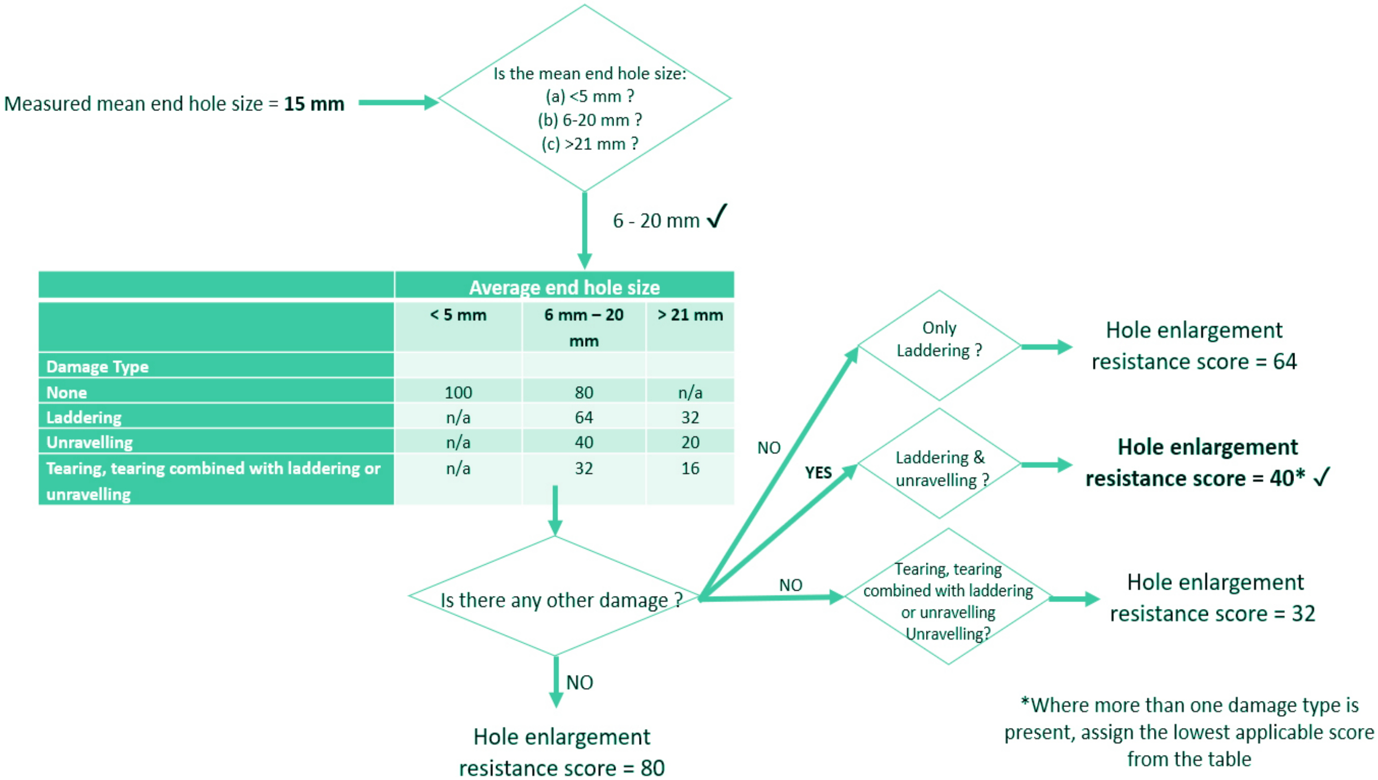
If samples of the same ITN exhibit different types of secondary damage, then report the hole enlargement resistance score that corresponds to the most serious type of damage observed in the samples, (i.e. the damage type giving the lowest score).

Table 2. Hole enlargement resistance score

Damage type	**Average end hole size**		
	< 5 mm	**6 mm – 20 mm**	**> 21 mm**
None	**100**	**80**	**n/a**
Laddering	**n/a**	**64**	**32**
Unravelling	**n/a**	**40**	**20**
Tearing/tearing combined with laddering or unravelling	**n/a**	**32**	**16**

For example, referring to Table 2, if the average end hole size for a net is 15 mm and both laddering and unravelling are present, the hole enlargement resistance score will be 40 (as unravelling is associated with a lower hole enlargement resistance score than laddering; 40 < 64). Determination of the hole enlargement resistance score is shown in Figure 11.

Figure 11. Flowchart for selecting the hole enlargement resistance score.



	Average end hole size		
	< 5 mm	6 mm – 20 mm	> 21 mm
Damage Type			
None	100	80	n/a
Laddering	n/a	64	32
Unravelling	n/a	40	20
Tearing, tearing combined with laddering or unravelling	n/a	32	16

7. Results

7.1. Recording and interpretation of results

Record:

1. Average end hole size.
2. Any observed secondary failure (laddering, unravelling or tearing).
3. Hole enlargement resistance score.

7.2. Considerations for the presentation of results

Table 3 gives an example of how the raw data for a sample should be recorded.

Table 3. Example of test data for a homogeneous ITN with a total number of 60 samples.

Sample Number	End hole size (mm)	Secondary failure				Hole enlargement score
		None	Laddering	Unravelling	Tearing	
1	10	Y	N	N	N	
2	11	Y	N	N	N	
3	13	N	Y	N	Y	
4	10	Y	N	N	N	
5	12	N	Y	N	N	
6	10	N	N	Y	N	
7	12	N	Y	N	Y	
8	13	Y	N	N	N	
9	15	Y	N	N	N	
10	14	N	Y	N	N	
11	13	Y	N	N	N	
12	10	Y	N	N	N	
13	11	N	Y	N	N	
14	16	Y	N	N	N	
15	20	N	Y	N	Y	
16	9	N	Y	N	N	
17	10	N	Y	N	N	
18	12	N	N	Y	N	
19	9	N	Y	N	N	
20	11	N	N	Y	N	
21	9	Y	N	N	N	
22	11	Y	N	N	N	
23	12	Y	N	N	N	
24	14	N	Y	N	Y	
25	13	N	N	Y	N	
26	12	N	Y	N	N	
27	9	N	Y	N	N	
28	10	N	N	Y	N	
29	15	N	Y	N	N	
30	19	N	N	Y	N	

31	11	N	Y	N	N	
32	12	N	Y	N	N	
33	14	N	N	Y	N	
34	11	N	Y	N	N	
35	13	N	N	Y	N	
36	11	Y	N	N	N	
37	13	Y	N	N	N	
38	14	Y	N	N	N	
39	16	N	Y	N	Y	
40	15	N	N	Y	N	
41	14	N	Y	N	N	
42	11	N	Y	N	N	
43	12	N	N	Y	N	
44	17	N	Y	N	N	
45	21	N	N	Y	N	
46	13	Y	N	N	N	
47	15	Y	N	N	N	
48	14	N	Y	N	Y	
49	13	Y	N	N	N	
50	10	N	Y	N	N	
51	11	N	N	Y	N	
52	16	N	Y	N	Y	
53	20	Y	N	N	N	
54	12	Y	N	N	N	
55	13	N	Y	N	N	
56	15	Y	N	N	N	
57	12	Y	N	N	N	
58	14	N	Y	N	N	
59	12	Y	N	N	N	
60	14	N	Y	N	Y	
Average	12.9	**Tearing combined with laddering or unravelling**				32

8. Test Report

The test report should include:

1. Sample details and identity.
2. The date the test is conducted.
3. Testing machine manufacturer and model.
4. The test operator.
5. The location and laboratory.
6. The conditions of testing if outside the testing conditions outlined in this document.
7. The pressure (kPa) at which the test is undertaken.
8. The end hole sizes after testing, and the average end hole size.
9. The presence of any secondary damage.
10. The hole enlargement resistance score.

9. Related Documents

- WHO PQT/VCP Implementation guidance - Declaration of ITN construction and sampling Procedure
- WHO PQT/VCP Implementation guidance - Data requirements table – Module 3
- WHO PQT/VCP Implementation guidance – IG - Snag strength
- WHO PQT/VCP Implementation guidance – IG - Abrasion
- Physical testing requirements for ITNs: Accreditation and compliance with international standards for the generation of data intended to be submitted to WHO prequalification

10. References

When using the normative references for physical tests, the updated version of the standard should always be used when available.

1. Wheldrake A, Guillemois E, Arouni H, Chetty V, Russell SJ. The causes of holes and loss of physical integrity in long-lasting insecticidal nets. Malar J. 2021;20:45. doi.org/10.1186/s12936-020-03567-0.
2. International Organization for Standardization. ISO 139:2005. *Textiles – Standard atmospheres for conditioning and testing*. Geneva: ISO; 2005.
3. Example of wound position on warp knitted ITN fabric structure A. 15th December 2023, Leeds (UK), Phys/Chem tests for ITNs: Hole enlargement resistance, NIRI/Technical Team, Nonwovens Innovation & Research Institute (NIRI Ltd.).
4. Example of wound position on warp knitted ITN fabric structure B. 15th December 2023, Leeds (UK), Phys/Chem tests for ITNs: Hole enlargement resistance, NIRI/Technical Team, Nonwovens Innovation & Research Institute (NIRI Ltd.).

5. Example of measuring the wounded area after testing (the end hole size) in structure A. In this example the end hole measures 17 mm. 15th December 2023, Leeds (UK), Phys/Chem tests for ITNs: Hole enlargement resistance, NIRI/Technical Team, Nonwovens Innovation & Research Institute (NIRI Ltd.).
6. Example of measuring the wounded area after testing (the end hole size) in structure B. In this example the end hole measures 30 mm. 15th December 2023, Leeds (UK), Phys/Chem tests for ITNs: Hole enlargement resistance, NIRI/Technical Team, Nonwovens Innovation & Research Institute (NIRI Ltd.).
7. Structure A. Example of laddering. Multiple unlooped yarns are visible - two or more unlooped yarns associated with a ladder. 15th December 2023, Leeds (UK), Phys/Chem tests for ITNs: Hole enlargement resistance, NIRI/Technical Team, Nonwovens Innovation & Research Institute (NIRI Ltd.).
8. Structure B. Example of unravelling. Two empty loops are visible caused by unravelling. 15th December 2023, Leeds (UK), Phys/Chem tests for ITNs: Hole enlargement resistance, NIRI/Technical Team, Nonwovens Innovation & Research Institute (NIRI Ltd.).
9. Structure B. Further example of unravelling. Multiple empty loops are visible. 15th December 2023, Leeds (UK), Phys/Chem tests for ITNs: Hole enlargement resistance, NIRI/Technical Team, Nonwovens Innovation & Research Institute (NIRI Ltd.).
10. Structure A. Example of a tearing (broken rungs). 15th December 2023, Leeds (UK), Phys/Chem tests for ITNs: Hole enlargement resistance, NIRI/Technical Team, Nonwovens Innovation & Research Institute (NIRI Ltd.).

11. Bibliography

- Wheldrake A, Guillemois E, Arouni H, Russell SJ. Textile testing to assess the resistance to damage of long-lasting insecticidal nets for malaria control and prevention. Malar J. 2021;20:47. doi: 10.1186/s12936-020-03571-4.
- British Standards Institution. BS 3424-38:1998. *Testing Coated fabrics. Determination of wounded bursting strength*. London: BSI group; 1998.
- International Organization for Standardization. ISO 13938-2:1999. *Textiles – Bursting properties of fabrics. Pneumatic method for determination of bursting strength and bursting distension.* Geneva: ISO; 1999.