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Evaluation of the anti-perforation textile insole test method following the standard NF EN ISO 20344 : 2012

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Evaluation of the anti-perforation textile insole test method following the standard NF EN ISO 20344 : 2012

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Evaluation of the anti-perforation textile insole test method following the standard NF EN ISO 20344 : 2012

Summary

A study was performed following accidents on worksites where employees had their feet perforated by nails, despite wearing anti-perforation shoes. The objective of the study was to evaluate the test of penetration resistance coming from the standard NF EN ISO 20344: 2012 and to develop a new test method adapted to textile inserts and representative of real use conditions. To do this, it was necessary to evaluate the following parameters:

- the limit value of perforation force to protect employees,
- nail geometry: shape, diameter, angle, truncation,
- penetration velocity,
- sample clamping platen hole diameter.

The INRS recommends a new limit value of 1300N for perforation force and the modification of the nail. Its choice is a nail with a pyramidal shape, with a diameter of 3 mm, a truncation of 1mm and an angle of 30°.

Five inserts taken from the market were tested and none of them satisfied these new recommendations.

For the tests of steel inserts in the standard NF EN ISO 20344: 2012, the nail is well dimensioned and is not called into question.

Evaluation of the anti-perforation textile insole test method following the standard NF EN ISO 20344 : 2012

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1. Introduction

Following the request made by the Caisse Régionale d'Assurance Maladie d'Ile de France (CRAMIF), INRS learned of two work accidents that had occurred on worksites: two employees had their feet perforated by a nail while wearing safety shoes comprising anti-perforation insoles, also called "inserts", made of composite material. The diameter and length of the nail in the first accident was 3.1 mm and 71 mm, respectively, and the employee weighed 96 kg. We do not have any information on the second accident.

The performances and properties required for shoes for general use and designed to protect feet are provided by a series of three standards:

- NF EN ISO 20345: 2012 [1] (EN ISO 20345 : 2011) for safety footwear,
- NF EN ISO 20346: 2004 [2] (EN ISO 20346 : 2004) for protective footwear,
- NF EN ISO 20347: 2012 [3] (EN ISO 20347 : 2012) for occupational footwear.

The difference between these three types of shoe concerns the level of protection ensured by the protective toe cap (see fig. 1):

Fig. 1. The different components of a safety shoe.

The test methods are described in standard NF EN ISO 20344: 2012[1] [4] (EN ISO 20344: 2012).
Standard NF EN 12568: 2010[1] [5] (EN 12568: 2010) specifically covers the requirements and test methods for toe caps and anti-perforation inserts. It has been drawn up to allow manufacturers to show the performance level of these components before they are inserted in the shoe.

Regarding textile anti-perforation inserts, these standards specify that "*When footwear is tested in accordance with ISO 20344, using a force of at least 1 100 N, the tip of the test nail*

[1] The standards NF EN ISO 20344: 2012 and NF EN 12568: 2010 have respectively replaced the standards NF EN ISO 20344: 2004 and NF EN 12568: 1998. As fas as the resistance to perforation is concerned, changes focused on the distances between the points of perforation and the way of doing the test for textile insert. A nail was pushed, at a speed of 10 mm.min^{-1}, on the sole to the complete perforation. The value of the applied force was then relieved. In the standards NF EN ISO 20344: 2012 and NF EN 12568: 2010, a force of 1100N is applied at a speed of 10 mm.min^{-1} and the machine is stopped to examinate visually the sample and see if the perforation of the sole takes place. Standardized nail and the limiting value of resistance to perforation remained identical. Therefore, the study described in this report is as well valid for the standards NF EN ISO 20344 : 2012 and NF EN 12568 : 2010 as for the standards NF EN ISO 20344 : 2004 et NF EN 12568 : 1998.

shall not penetrate through the test piece. In order to achieve a "pass" result, the tip of the test nail shall not protrude from the test piece. This is to be checked by visual, cinematographic or electrical detection. If the opposite surface of the test piece has been penetrated, the test piece has failed the test. If separation between the layers of the test piece occurs ("tent effect") the test piece has failed the test."

INRS performed, in 2010, an initial study that was described in study report No. IET/10RI-199/MJs. The aim of this study was to verify the conformity to applicable standards of the shoe responsible for the work accident, analyze its behaviour regarding the perforation of several shoes taken as samples from the market and evaluate the pertinence of the standardized test method. It demonstrated that:

- the resistance to perforation of the shoe responsible for the accident was lower than the required minimum resistance,
- the shoes sampled from the market satisfied the specifications of the standard,
- the standardized test method, developed to test steel inserts, was not adapted for testing textile inserts.

A new study was performed in order to:

- evaluate the parameters of the standardized test influencing the perforation force and deformation of the insert,
- propose a test method adapted for textile inserts and representative of real use conditions.

This document presents the synthesis of the results and the conclusions of this study.

2. Bibliographical research

Bibliographical research was carried out on the mechanical parameters implemented when walking in order to check the pertinence of the limit value of perforation force and the penetration velocity required by the standard. We focused more specifically on the bearing force and the touchdown velocity of the foot in the framework of normal human walking.

2.1. Bearing force

The walking cycle is described in the literature:

"By convention, the walking cycle starts when the heel of a foot touches the ground and ends when the same heel next touches the ground; it comprises two main phases which are the bearing phase and the oscillating phase and lasts about 1 second" [6] (see fig. 2).

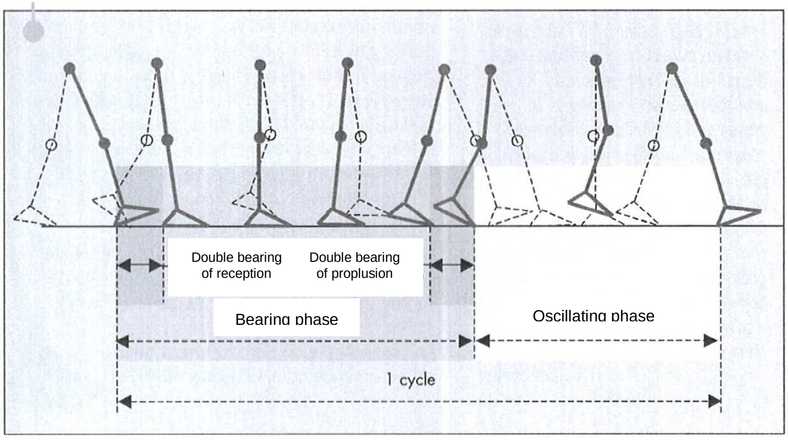


Fig. 2. Diagrammatic representation of the walking cycle and its main phases and sub-phases [6].

The bearing phase lasts 60% of the cycle and can be broken down into three sub-phases. The first sub-phase called the double contact phase lasts 10% of the cycle. *"The two feet are in contact with the ground. The foot that touches down is placed fully on the ground while the contralateral foot progressively leaves it. It is during this period that the weight of the body is transferred, increased by dynamic effect, from the contralateral bearing foot to the receiving foot"* [6]. The two other sub-phases are: the unilateral phase where a single foot touches down on the ground and heel-off at the end of the phase and the double contact phase where *"both feet are once again simultaneously in contact with the ground and the bearing foot pushes backwards and sidewards to propel the body forwards and towards the contralateral foot that will receive the weight of the body"* [6].

In their article [7], E.M. LAASSEL & al. focused on the reaction forces of the foot during normal walking. They showed that the maximum force of the foot on the ground produces two peaks whose intensity varies from 80 to 140% of the weight of the person (window 3 of fig. 3).

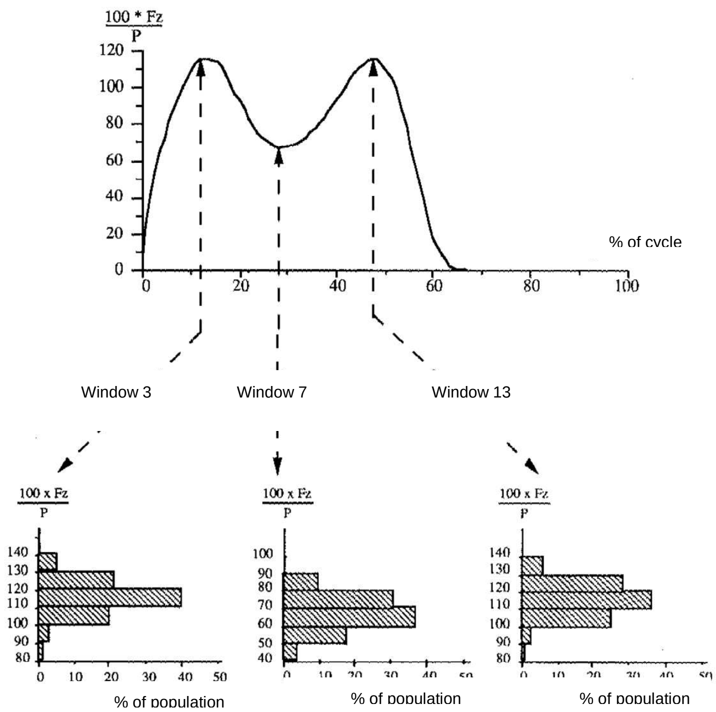


Fig. 3. Fz/P ratio curves (vertical reaction/weight) as a function of the walking cycle and distributions for windows 3, 7 and 13 [7].

On the basis of these results, by considering the worst case (walking with a maximum peak of 140%), the standardized limit value of perforation resistance of 1100N corresponds to a force applied by a person of 80 kg.

This weight of 80 kg is slightly higher than the average value for men (77.4 kg) evaluated during the measurement campaign performed in France by the IFTH[1] in 2006 [8] and does not permit taking into account the additional weight represented by carrying materials and tools (bags of cement of 25 to 35 kg, tool boxes, etc.) by employees when working. Thus the standard value of resistance to perforation of 1100N only allows protecting some of the people present on a worksite.

Table 1 gives the applied force in the case where the maximum peak of walking reaches 115% (average value) and 140% (maximum value), as a function of a total employee weight varying from 80 to 120 kg. The total weight of the employee is understood as including carried weight.

Total weight of employee (kg)	Applied force (maximum peak at 115%) (N)	Applied force (maximum peak at 140%) (N)
80	905	1100
90	1015	1240
100	1130	1375
110	1240	1510
120	1355	1650

Table 1. Applied forces as a function of the total weight of an employee and the maximum peak during walking.

It can be seen that a person weighing 75 kg carrying a bag of cement of 35 kg would require an insert resisting a minimum force of 1240N and 1510N respectively in the case where the maximum force reaches 115% and 140%.
The maximum force applied at the moment of contact of the foot with the ground depends not only on the weight but also the speed of the person. The present study is limited to persons walking on worksites. Readers can refer to De Wit B. et al. [9] who analyzed the applied force/weight ratio as a function of the subject's speed. For a run at 3.5 $m.s^{-1}$ (i.e. 13 $km.h^{-1}$), this ratio is in the region of 1.8. It can reach a value of 2.8 for a run at 5.5 $m.s^{-1}$ (i.e. 16 $km.h^{-1}$). According to this article, it can be estimated that for a person weighing 80 kg, the maximum applied force can vary from 1400 to 2200N during a run for speeds ranging from 3.5 and 5.5 $m.s^{-1}$. The case of running is not taken into account in this study but it permits emphasising the influence of the person's velocity on the applied force.

It appears pertinent to increase the limit value of the standard considerably to 1300N, corresponding to a person weighing 95 kg walking with a maximum peak at 140%.

2.2. Foot touchdown velocity

Our bibliographical research did not identify any articles evaluating foot touchdown velocity. However, it can be calculated on the basis of known data on walking and on human morphology. The aim is to determine, initially, the distance travelled by the toe tip and the time the foot takes to land on the ground. The ratio of these two values permits deducing the foot touchdown velocity.

[1] IFTH: Institut Français du Textile et de l'Habillement.

The IFTH measurement campaign of 2006 indicated that the foot of a man measures between 20.6 cm and 32.3 cm. Furthermore, the angle made by the ankle with the ground at the moment the heel lands is 20° [10]. The distance travelled by the toe tip therefore varies from 7 to 11 cm.

The walking speed of a man varies from 75 and 140 steps/min [11] and the bearing phase corresponds to 10% of walking time. The time taken for the downwards step is therefore between 0.04 and 0.08 s.

It can therefore be estimated that the touchdown velocity of the foot varies between 0.88 and 2.56 $m.s^{-1}$, i.e. from 5 to 15 10^4 $mm.min^{-1}$. This velocity is therefore very far from the penetration velocity of 10 $mm.min^{-1}$ chosen in the standard. Tests with a higher penetration velocity will be considered.

3. Methodology

3.1. Test bench and protocol

The perforation tests were performed with a tensile testing machine used to measure the perforation force and the deformation of the insert.

An insert was clamped between two rigid platens (see fig. 4). These have a hole with a given diameter to allow the nail to pass through. The penetration velocity was determined and the penetration force and deformation were recorded during the experiment. The operator stopped the test when he visually detected the perforation of the insert, that is to say when the nail had just pierced the textile (see fig. 5).

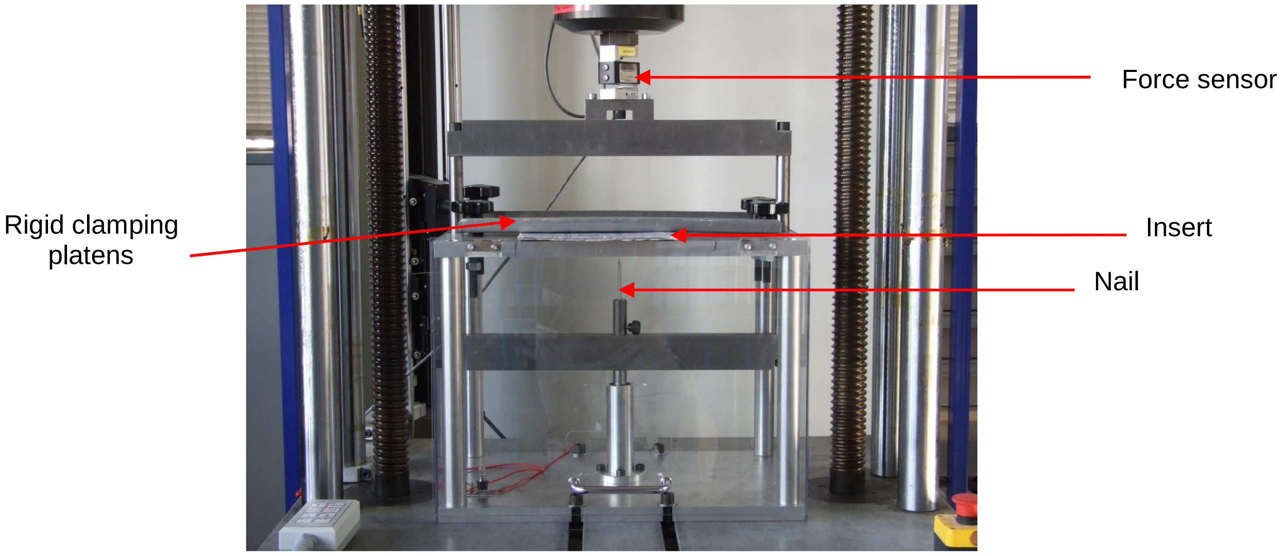


Fig. 4. Test bench.

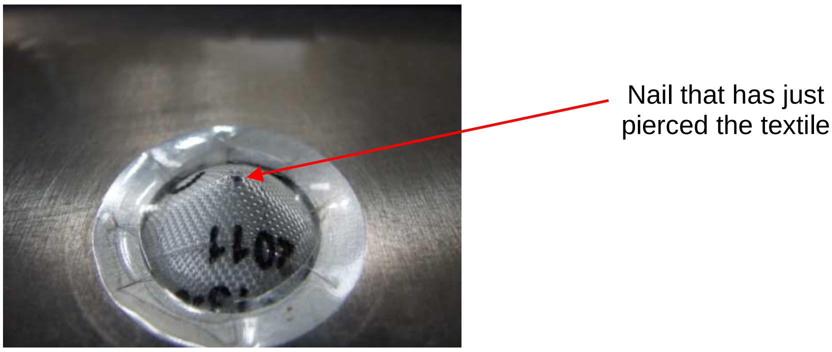


Fig. 5. Example of perforation of an insert.

The curve of nail displacement as a function of the force applied on the insert was recorded (see fig. 6). The perforation force corresponded to the maximum penetration force recorded at the moment of perforation. Deformation was calculated on the basis of the difference between the value of the displacement at the moment of first contact between the nail and the textile and that when the test was stopped.

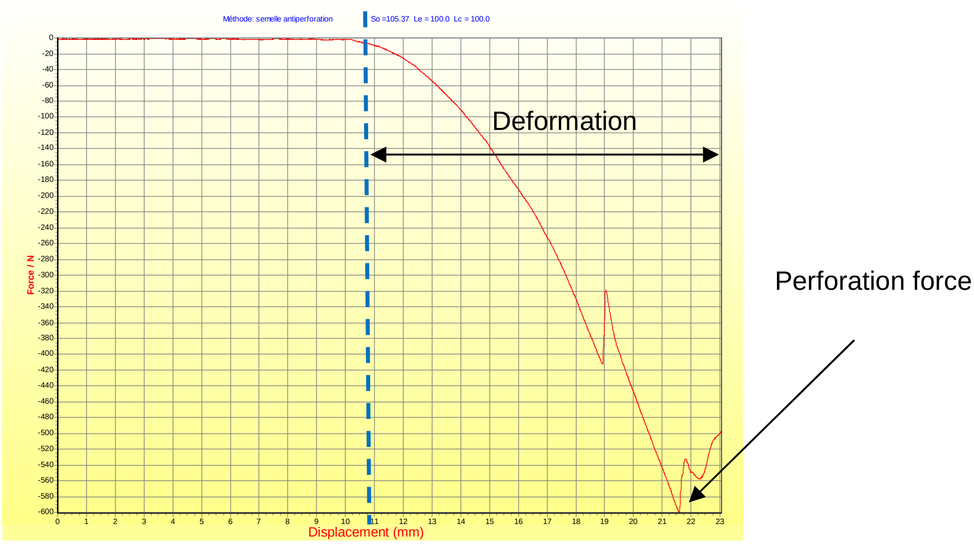


Fig. 6. Example of the curve of nail displacement as a function of force applied on the textile insert.

3.2. Study protocol

The different test parameters were studied to evaluate their influences on the perforation force and on the deformation of the insert. The tests were performed on a textile insert of average quality.

These parameters were fixed on the basis of the bibliographical analysis and test results, by taking the values considered to be the most pertinent. The validation tests were then performed on different types of textile insert of different qualities.

Ten measurements were performed for each of the test conditions considered.

Reproducibility and repeatability

To evaluate the repeatability and reproducibility of the tests, ten measurements were performed on the same insert, first with the same nail in conformity with the standard, then with a second nail identical to the first.

The test conditions were those specified by the standard: penetration velocity of 10 $mm.min^{-1}$ and a hole diameter of 25 mm for the clamping platens.

The perforation and deformation force at the moment of perforation were analyzed to determine the precision of the measurements.

Nail geometry

The standard nail is cylindrical with a diameter of 4.5 mm, the tip is conical with a truncation of 1 mm and an angle of 30°.

Following visits to worksites, it was seen that the standard nail was not representative of those found in situ. The characteristics of the latter were mainly the following: their diameter varied from 2.4 to 5 mm with most having a diameter of 3 mm, they varied in length from 50 to 110 mm, and their tips were mainly pyramidal in shape, with a truncation of more than 1 mm and often with angles exceeding 30°. Several screw s and other nails with conical tips were also found.

The nails were characterized by the following parameters: nail diameter, shape, truncation and tip angle (see fig. 7).

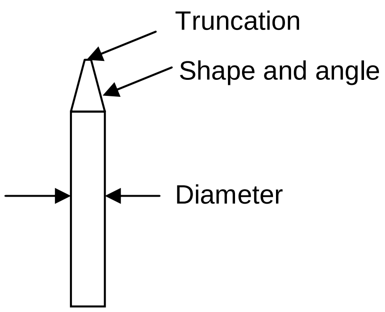


Fig. 7. Nail characteristics.

Different test nails were chosen to cover the following characteristics:

- tip shape: pyramidal (P) and conical (C),
- nail diameter: 2.5, 3 and 4.5 mm (D2.5, D3 and D4.5),
- truncation: 0, 1 and 2 mm (T0, T1 and T2),
- tip angle: 15°, 30° and 45° (A15, A30 and A45).

The nails used in the study are listed in table 2. They were manufactured especially in a workshop to ensure the precision and reproducibility of the parameters. The material was steel of hardness HRC ≥60 as specified by the standard.

The nails are identified as follows in the rest of the document: tip shape – diameter – truncation – tip angle. The standardized, conical nail, of diameter 4.5 mm, truncation 1 mm and angle 30° is called C-D4.5-T1-A30.

Nail	Tip shape	Diameter (mm)	Truncation (mm)	Angle (°)
C-D4.5-T0-A30	C	4.5	0	30
C-D4.5-T1-A30	C	4.5	1	30
C-D4.5-T2-A30	C	4.5	2	30
P-D4.5-T0-A30	P	4.5	0	30
P-D4.5-T1-A30	P	4.5	1	30
P-D4.5-T2-A30	P	4.5	2	30
C-D4.5-T0-A15	C	4.5	0	15
C-D4.5-T1-A15	C	4.5	1	15
C-D4.5-T0-A45	C	4.5	0	45
C-D4.5-T0-A45	C	4.5	1	45
P-D2.5-T1-A30	P	2.5	1	30
P-D3-T1-A30	P	3	1	30

Table 2. Characteristic of the nails used for the study.

Three nails are shown in fig. 8.

C-D4.5-T1-A30 P-D4.5-T1-A30 C-D4.5-T0-A15

Fig. 8. Examples of nails with different geometries.

To evaluate the influence of nail geometry, the tests were performed with a penetration speed of 10 $mm.min^{-1}$ and a hole diameter for the clamping platens of 25 mm.

Penetration speed

Two penetration speeds were considered: 10 $mm.min^{-1}$ (standard value) and 400 $mm.min^{-1}$. The latter value corresponded to the highest speed starting from which it became difficult to detect the precise moment of perforation.

Sample clamping platen hole diameter

In order to determine the influence of the insert holder, the tests were performed with three different sample clamping platen hole diameters: 12.5, 25 and 50 mm.

Different insert qualities

New test parameters were fixed on the basis of the investigations performed previously.

The tests were then carried out on 5 types of textile insert of different qualities and origins, with two new nails selected from those tested to validate their pertinence. These tests also permitted evaluating the behaviour of the inserts vis-à-vis these nails.

In addition, they were carried out with the standard conical nail to compare the perforation forces obtained under current and new test conditions.

4. Results

The results are presented in the form of Tukey box and whisker plots that permit identifying the following data (see fig. 9):

- the scale of values of the variable, located on the vertical axis.
- the value of the 1st quartile Q1 (25% of samples), corresponding to the lower line of the box;
- the value of the median (50% of samples), represented by a horizontal line inside the box,
- the average value, indicated by a cross,
- the value of the 3rd quartile Q3 (75% of samples), corresponding to the upper line of the box,
- the 2 lower and upper "whiskers" delimiting the adjacent values. These are determined on the basis of the interquartile range (Q3-Q1).
- the values deemed extreme, atypical and exceptional located beyond the adjacent values are individualized. They are presented by a square.

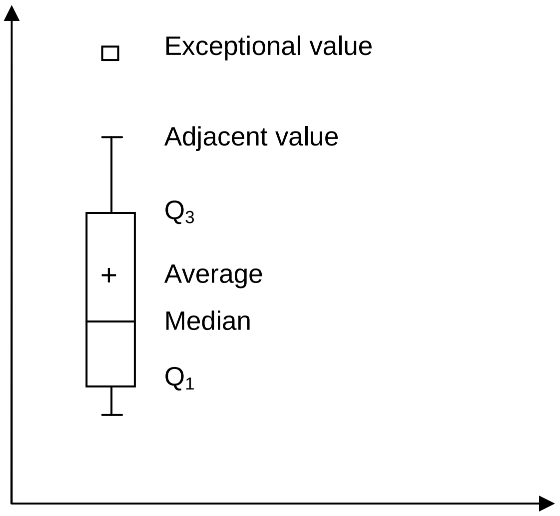


Fig. 9. Tukey box and whisker plot.

The results are completed by a table indicating the average value, the standard deviation and extreme values (minimum and maximum) for the variable considered.

4.1. Repeatability and reproducibility of tests

Perforation force

Fig. 10 presents the results of the perforation force obtained with two samples of the standard nail and table 3 gives the average and extreme values and the standard deviations of this variable.

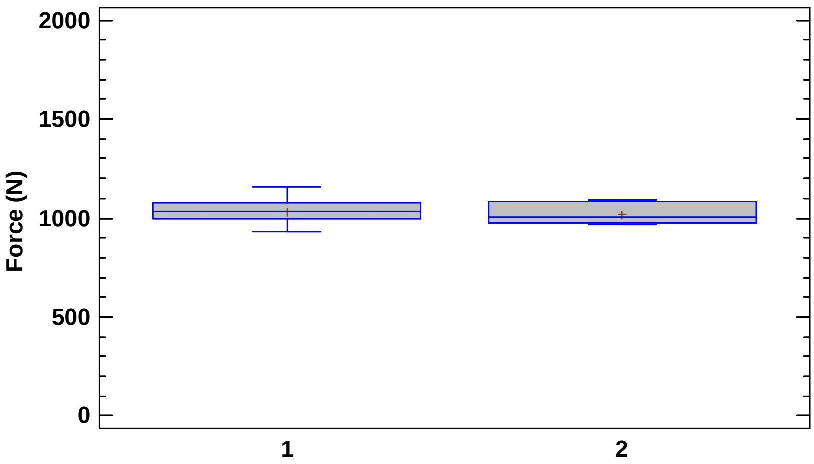


Fig. 10. Perforation forces for two standardized nails C-D4.5-T1-A30.

Nail C-D4.5-T1-A30	Average force (N)	Standard deviation	Minimum force (N)	Maximum force (N)
1	1036	67	932	1157
2	1020	53	965	1092

Table 3. Perforation forces for two standardized nails.

Regarding repeatability, for the same nail the standard deviation is in the region of 60N and the variance between the minimal and maximum forces is a little higher than 230N. By taking 2 standard deviations, we can estimate that the results regarding the perforation forces are precise to ±120N.

The average values of the perforation force obtained with the two nails are respectively 1036N and 1020N. This variance is negligible in comparison to the variance of repeatability. Good reproducibility is ensured from one nail to another.

Deformation

The insert deformation results are shown in fig. 11 and the average and extreme values and standard deviations in table 4.

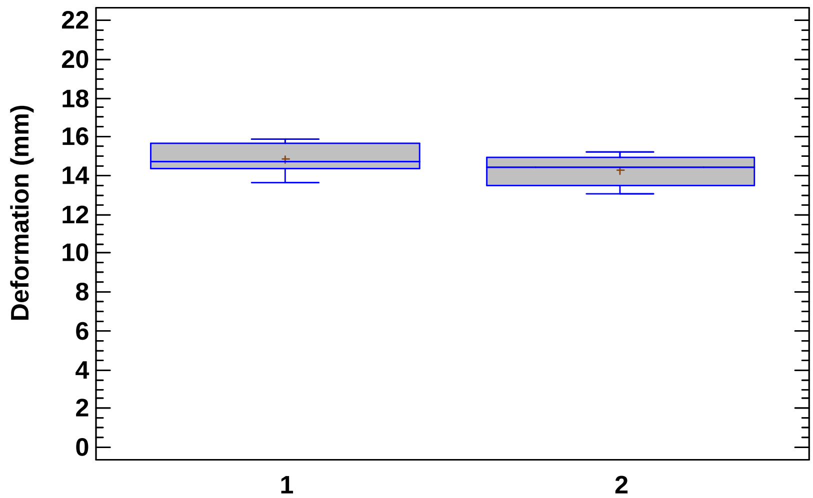


Fig. 11. Deformations of the insert for two standardized nails C-D4.5-T1-A30.

Nail C-D4.5-T1-A30	Average deformation (mm)	Standard deviation	Minimum deformation (mm)	Maximum deformation (mm)
1	14.8	0.8	13.6	15.9
2	14.3	0.8	13.0	15.2

Table 4. Deformations of the insert for two standardized nails.

Regarding repeatability, the standard deviation is in the region of 0.8 mm and the variance between the minimum and maximum deformations is slightly higher than 2.3 mm. By taking 2 standard deviations, we can estimate that the results for the deformations are precise to ±1.6 mm.

The average deformation values obtained with the two nails are 14.8 and 14.3 mm respectively. This variance is negligible in comparison to the variance of repeatability. Good reproducibility is ensured from one nail to another.

4.2. Nail geometry

Influence of shape, truncation and angle of the nail tip

Perforation force

Fig. 12 and table 6 in appendix B present the perforation force obtained with conical and pyramidal nails whose tips have different truncation values (0, 1 and 2 mm). The diameter and tip angle are the same for the 6 nails.

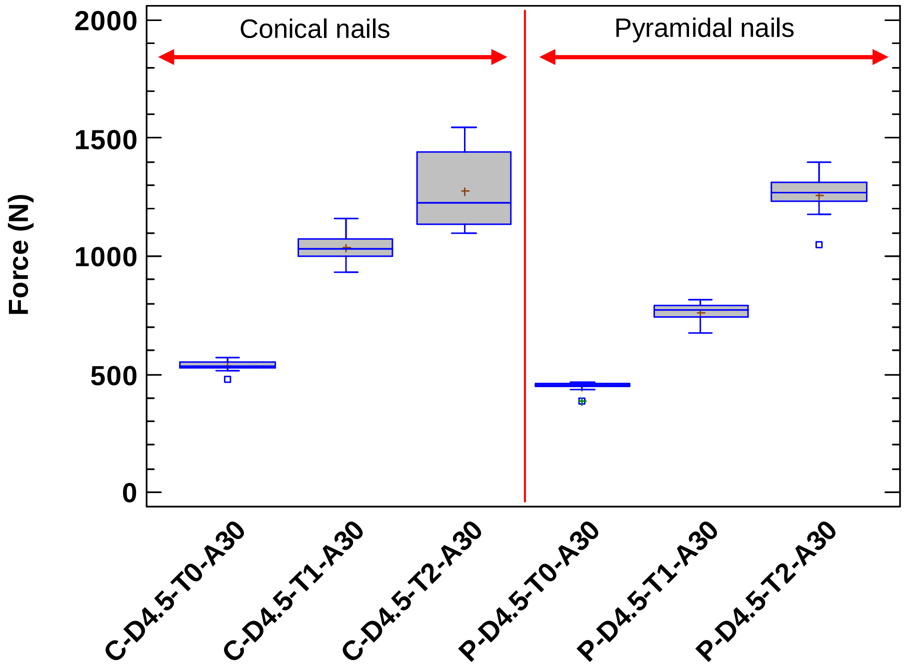


Fig. 12. Perforation forces as a function of nails with different shapes and truncations.

Perforation force varies significantly as a function of the geometry of the nails used.
For the same nail geometry, the more truncated the tip, the higher the perforation force is. This can be explained by the fact that a fine nail slides between the mesh of the textile, contrary to a very truncated nail which will be stopped by the threads of the textile.

For the same truncation, less force is required for a pyramidal nail to perforate the textile insert than for a conical nail.

Fig. 13 and table 7 in appendix B present the perforation force obtained with conical nails with tips having different truncation values (0 and 1 mm) and angles (15°, 30° and 45°). The 6 nails have the same diameter.

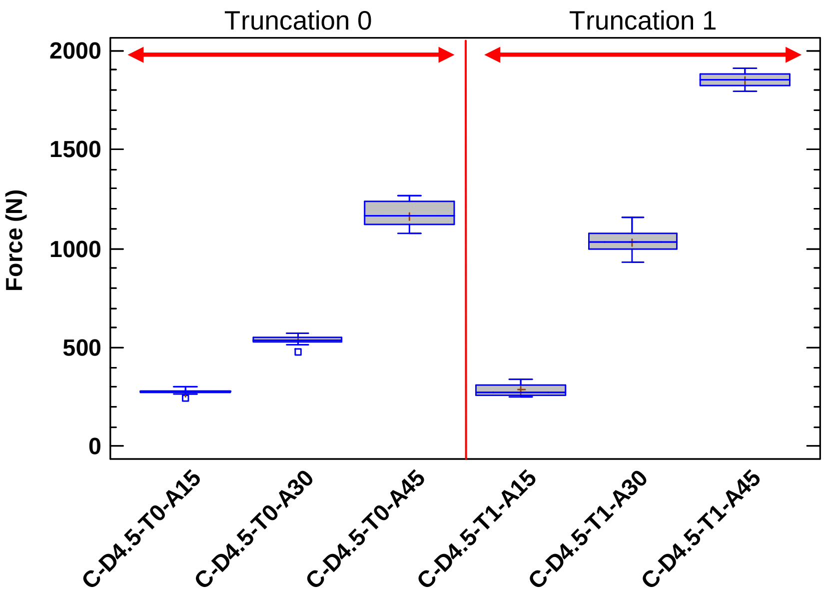


Fig. 13. Perforation forces as a function of different tip angles and truncations.

The angle of the nail tip has a very strong influence on perforation force. A more acute angle required less force to perforate the inserts. For nails with a truncation of 1 mm, the perforation force with a nail of 15° and that for an angle of 45° differs by a factor of 6. This parameter will have to be chosen with care in order to choose the nail most representative of those on the worksite.

Deformation

Fig. 14 and table 8 in appendix B present deformations obtained with conical and pyramidal nails whose tips have different truncation values (0, 1 and 2 mm). The diameter and tip angle are the same for the 6 nails.

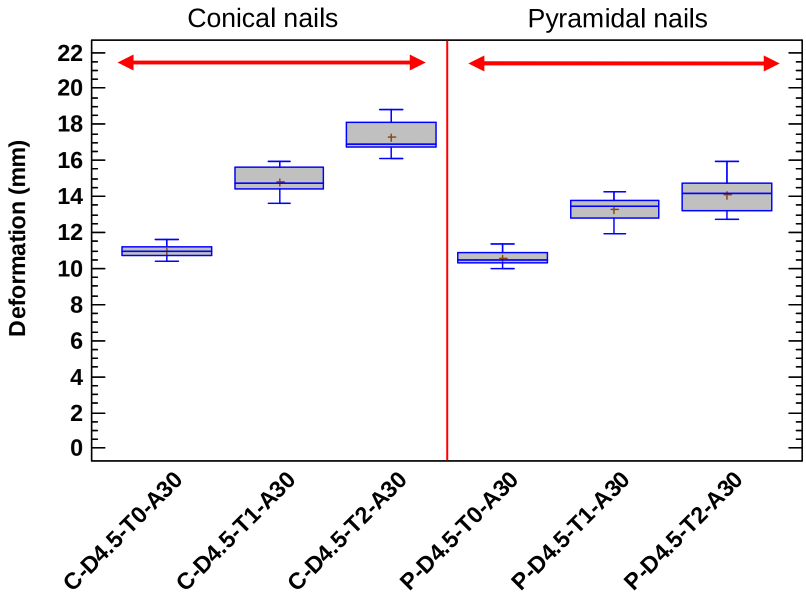


Fig. 14. Insert deformations as a function of nails with different shapes and truncations.

Fig. 15 and table 9 in appendix B present the deformations obtained with conical nails whose tips have different truncation values (0 and 1 mm) and angles (15°, 30° and 45°). The diameter was the same for the 6 nails.

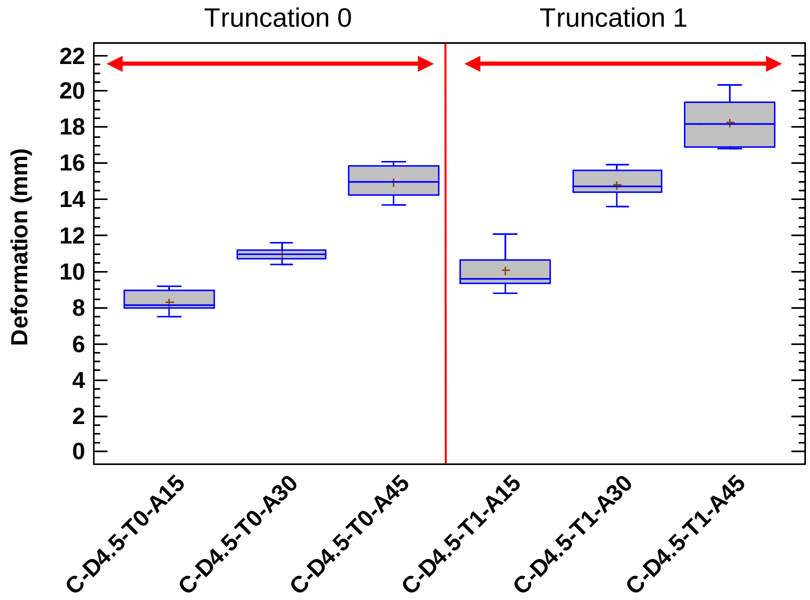


Fig. 15. Deformations of the insert as a function of different nail angles and truncations.

Fig. 12 and 13, compared to fig. 14 and 15, respectively, show that the deformation of the insert increases when the perforation force increases.

Nail geometry has the same influence on deformation and on perforation force:

- for the same nail geometry, the more truncated the tip, the greater the deformation,
- deformation is greater for a conical nail than for a pyramidal nail,
- more acute angles lead to less deformation.

These tests demonstrated the considerable influence of the shape of the nail tip on perforation force and the deformation of the inserts. We therefore carried out the following tests with the standard nail and nails as similar as possible to those found on the worksite, i.e. nails with a pyramidal tip, with an angle of 30° and a truncation of 1 mm.

Influence of nail diameter

We only studied the influence of the diameter on the perforation force, using pyramidal nails. Fig. 16 and table 10 in appendix B present the perforation force obtained with pyramidal nails of diameters of 2.5, 3 and 4.5 mm. The tip angle was 30° and the truncation 1 mm.

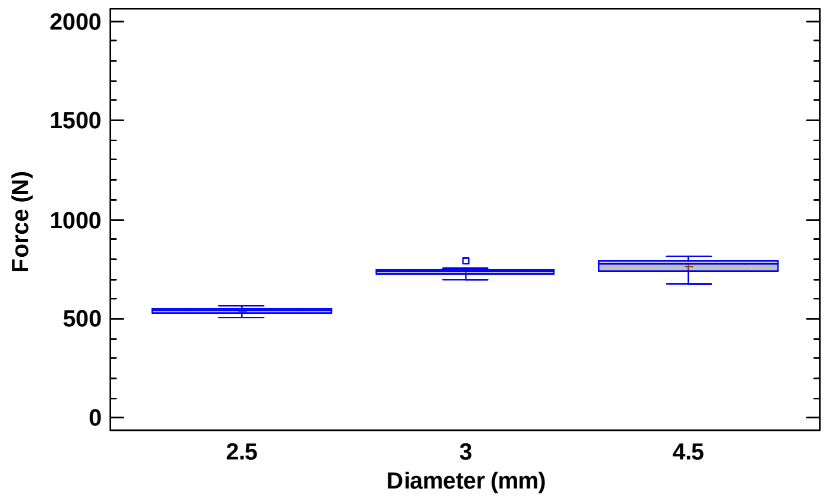


Fig. 16. Perforation forces as a function of nail diameter, pyramidal tip, a truncation of 1 mm and an angle of 30°.

It can be seen that the perforation force diminishes as the diameter decreased. This trend was less marked when changing from a diameter of 4.5 mm to 3 mm.

4.3. Penetration velocity

Fig. 17 and table 11 in appendix B present the perforation force obtained with conical and pyramidal nails with a diameter of 4.5 mm, with a tip having a truncation of 1 mm and an angle of 30°.

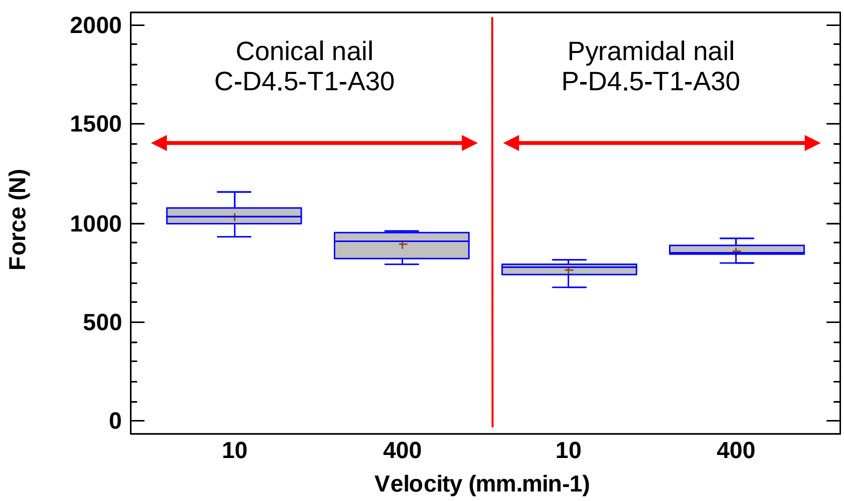


Fig. 17. Perforation forces for two different penetration velocities.

Regarding the conical nail, the perforation forces were higher for a velocity of 10 mm.min^{-1} than for one of 400 mm.min^{-1}. The reverse was observed for pyramidal nail.

It was not possible to perform tests at a higher velocity: visual detection of perforation was very difficult with a penetration velocity of 400 mm.min^{-1}. Furthermore, the number of points recorded by the tensile testing machine was lower, leading to a reduction in the precision of the results.

Setting up a dynamic test made it possible to draw close to the penetration velocities reached during accidents. This required defining, beforehand, a perforation detection system compatible with the velocity implemented. As yet no simple and reproducible system has been found, so at present no dynamic test is available for this purpose.

Given the results, there is no plan to increase the penetration velocity in this test method.

4.4. Sample clamping platen hole diameter

<u>Perforation force</u>

Fig. 18 and table 12 in appendix B present perforation force as a function of different sample clamping platen hole diameters with conical and pyramidal nails, having a diameter of 4.5 mm, with tips truncated at 1 mm and an angle of 30°.

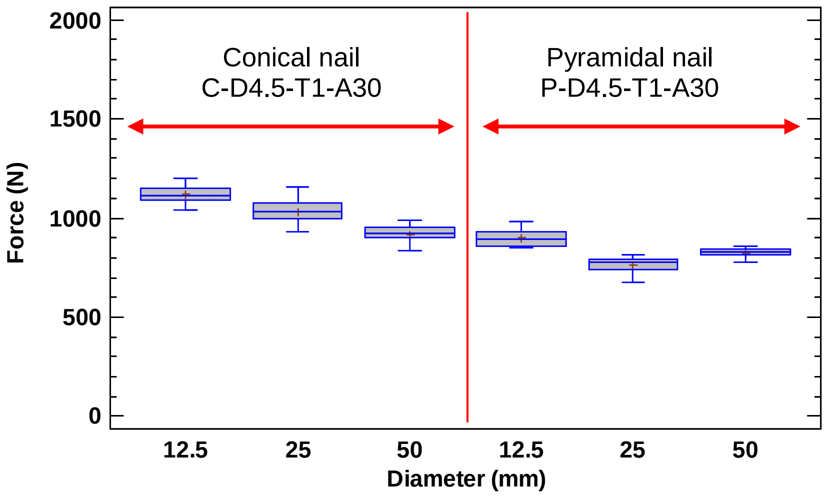


Fig. 18. Perforation forces for different sample clamping platen hole diameters.

A slight decrease can be observed in perforation forces for the conical nails.
Regarding the pyramidal nails, perforation force decreased when the sample clamping platen hole diameter is increased from 12.5 to 25 mm. This trend is reversed when it is changed from 25 to 50 mm, though with a moderate impact.

<u>Deformation</u>

Fig. 19 and table 13 in appendix B give the deformation of the insert as a function of the different sample clamping platen hole diameters with conical and pyramidal nails.

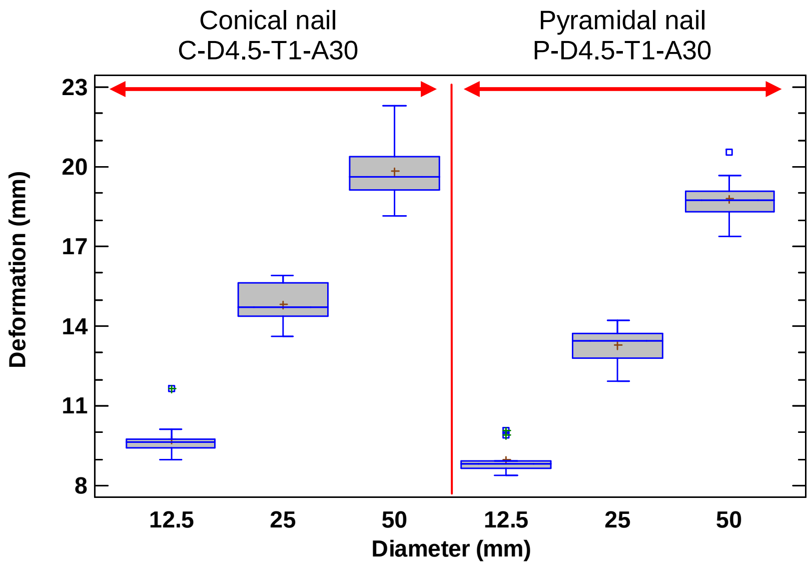


Fig. 19. Deformations as a function of the sample clamping platen hole diameters.

Whatever the geometry of the nail (conical or pyramidal), deformation increases by a factor from 1 to 2 when the sample clamp hole diameter is changed from 12.5 to 50 mm.
Given the perforation forces measured with the pyramidal nails, the diameter of 25 mm appeared pertinent and can be conserved.

4.5. Insert quality

Perforation force

Fig. 20 and table 14 in appendix B give the perforation force obtained by 5 types of inserts of different origins and quality, by using the standard nail and two pyramidal nails of diameters of 3 and 4.5 mm. The inserts are described in table 5. Insert no. 1 is that which was used to produce the previous results.

Insert no.	Supplier	Thickness (mm)	Surface density ($g.m^{-2}$)
1	A	3.2	3153
2	A	3.9	2701
3	B	4.0	3798
4	B	4.0	6039
5	C	3.7	3592

Table 5. Insert characteristics.

For these tests, the penetration velocity was 10 $mm.min^{-1}$ and the sample clamping platen hole diameter was 25 mm.

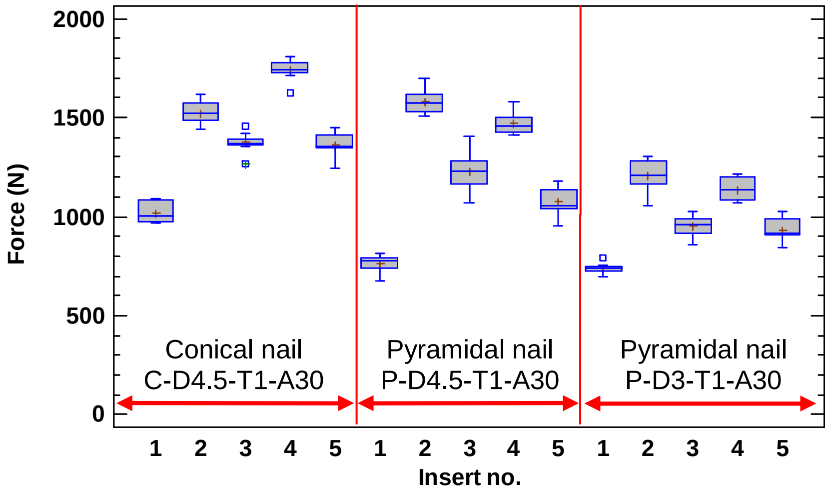


Fig. 20. Perforation forces as a function of insert quality.

The following results can be noted:

- The same results as before were obtained: for the same diameter, the perforation forces remain lower for the pyramidal nail than for the conical nail, except for insert no. 2.

- The pyramidal nail with a diameter of 3 mm lead to a marked decrease of perforation force in comparison to that obtained with the pyramidal nail with a diameter of 4.5 mm, except for insert no. 1. Diameter has a strong influence on perforation force. It has to be representative of most of the nails found on the worksite, i.e. with a diameter of 3 mm.

- For the standardized nail, only insert no. 1, chosen for all the tests, do not permit reaching the value of 1100N recommended by the standard. For inserts nos. 3 and 5, the average perforation force is over 1300N, with some values below this limit. Inserts nos. 2 and 4 resist perforation forces higher than 1400N.

- For the pyramidal nail with a diameter of 4.5 mm, only inserts nos. 2 and 4 are validated with the value of 1100N and remain validated for the recommended value of 1300N.

- With the pyramidal nail with a diameter of 3 mm, no insert is capable of reaching the value of 1300N. Inserts nos. 1, 3 and 5 do not resist the force of 1100N. For inserts nos. 2 and 4, the average perforation force is above 1100N, with some values below this limit.

Deformation

Fig. 21 and table 15 in appendix B present the deformation of 5 types of inserts, by using the standard nail and two pyramidal nails with diameters of 3 and 4.5 mm.

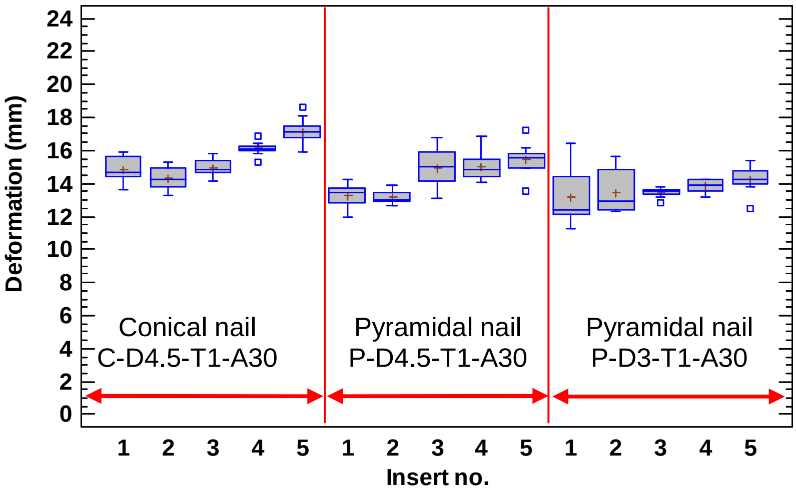


Fig. 21. Deformations as a function of insert quality.

The deformations varied from 12 and 19 mm for the different textile qualities and the different nails.

If all the inserts are taken into account, there is no relation between deformation and perforation force.

5. Conclusion

This study was focused on the standard test of penetration resistance for anti-perforation inserts described in the standards NF EN 20344: 2012 and NF EN 12568: 2010. The purpose was to evaluate the test parameters influencing the perforation force and the deformation of the insert and possibly propose a test method adapted to textile inserts and representative of real use conditions.

This study showed that:

- The limit value of resistance to perforation of 1100N, to which the inserts must conform to satisfy the standard, does not permit protecting all employees. INRS recommends raising this value to 1300N. This corresponds to the force applied by a person carrying a load with a total combined weight of 95 kg and incorporates the dynamic effect linked to walking.

- The conical nail with a diameter of 4.5 mm used in the standard is not sufficiently representative of the nails found on the worksite and underestimates the risk of perforation of the insert. Nail tip geometry is a very important parameter for the perforation and deformation forces generated. INRS recommends using a nail similar to the majority of those found on the worksite, that is to say a nail with a pyramidal tip with a diameter of 3 mm. The angle of 30° and the t runcation of 1 mm are retained.

- The magnitude of the penetration velocity within the range investigated (10 – 400 $mm.min^{-1}$) was not great. The velocity specified in the standard can be conserved in the framework of this static test.
  However, setting up a dynamic test would make it possible to draw close to the penetration velocities occurring during accidents. It would require defining, beforehand, a perforation detection system compatible with the velocity involved. However, no simple and reproducible system has been found as yet. Thus it is not possible to propose a dynamic test at present.

- The sample clamping platen hole diameter mainly influences the deformation of the insert though does not have a significant influence on the perforation force with a pyramidal nail. The current diameter of 25 mm can be conserved.

Five types of insert available on the market were tested. Four of them satisfied the specifications of the current standard. With the new nail recommended, only two inserts had an average perforation force slightly above 1100N. None resisted a force of 1300N.

The mechanisms of perforation of textile inserts and steel inserts are different. The current standard nail used for steel soles is well-dimensioned and is not called into question.

6. References

[1] NF EN ISO 20345 - Equipement de protection individuelle - Chaussures de sécurité. PARIS, AFNOR, Février 2012, 31 p.

[2] NF EN ISO 20346 - Equipement de protection individuelle - Chaussures de protection. PARIS, AFNOR, Octobre 2004, 13 p.

[3] NF EN ISO 20347 - Equipement de protection individuelle - Chaussures de travail. PARIS, AFNOR, Avril 2012, 13 p.

[4] NF EN ISO 20344 - Equipement de protection individuelle - Méthodes d'essais pour les chaussures. PARIS, AFNOR, Février 2012, 92 p.

[5] NF EN 12568 - Exigences et méthodes d'essais des embouts et des inserts anti-perforation. PARIS, AFNOR, Juillet 2010, 28 p.

[6] L'OBSERVATOIRE DU MOUVEMENT - La marche. La lettre de l'Observatoire du Mouvement, Avril 2004, 11, pp. 1-12.

[7] LAASSEL E.M., LOSLEVER P., VOISIN PH., HERLANT M. - multidirectionnelle des forces de réaction du pied au cours de la marche normale. Acta Orthopaedica Belgica, 58, 3, pp. 272-279.

[8] IFTH - Synthèse Textile-Habillement. Le journal des professionnels du Textile et de l'Habillement, Février 2006, N°12 - Hors série, p. 4.

[9] DE WIT B. et al. - Biomechanical analysis of the stance phase during barefoot and shot running. Journal of Biomechanics, 2000, 33, pp. 269-278.

[10] CAZEAU C. - ANALYSE BIOMÉCANIQUE D'UNE SPÉCIFICITÉ DE LA BIPÉDIE HUMAINE: la mise en flexion dorsale de la cheville lors de l'appui. Maîtrise Orthopédique n°166, août 2007.

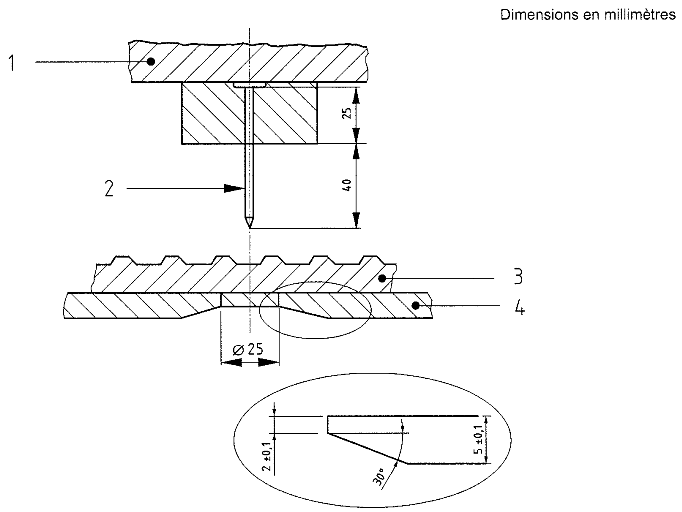
[11] BÉNICHOU J., LIBOTTE M. - Le livre du pied et de la marche. Odile Jacob, 2002, 338 p.

Appendix A

Standard textile insert perforation test NF EN ISO 20344: 2012

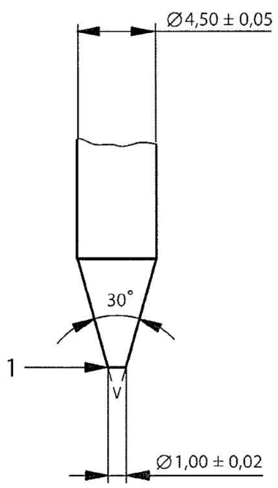
The test equipment (see fig. 22) is composed of a machine capable of generating and measuring compressive forces up to at least 2000 N, fitted with a pressure plate in which the test nail (see fig. 23) is fixed and a parallel plate pierced with a circular opening of diameter 25 mm holding the insole to be tested (test piece). The test nail has a diameter of (4.5 ± 0.05) mm, whose tip is truncated according to the shapes and dimensions shown in fig. 23.

The test nail is pressed into the test piece at a velocity of (10 ± 3) mm/min, until the required force of 1100 N is reached. The machine is stopped. The insole is examined by visual inspection or by electric or video detection to detect possible perforation.



1: Pressure plate
2: Nail
3: Part of insole to be tested
4: Lower plate

Fig. 22. Device used for the perforation resistance test.



1: Truncated tip

Fig. 23. Standard nail for the perforation resistance test.

Appendix B

Table of results

Influence of shape, truncation and angle of the nail tip

Perforation force

Nail	Average force (N)	Standard deviation	Minimum force (N)	Maximum force (N)
C-D4.5-T0-A30	534	25	479	571
C-D4.5-T1-A30	1036	67	932	1157
C-D4.5-T2-A30	1275	161	1101	1543
P-D4.5-T0-A30	447	23	386	467
P-D4.5-T1-A30	742	64	612	813
P-D4.5-T2-A30	1256	95	1050	1399

Table 6. Perforation forces as a function of different nail shapes and truncations.

Nail	Average force (N)	Standard deviation	Minimum force (N)	Maximum force (N)
C-D4.5-T0-A15	276	14	246	300
C-D4.5-T0-A30	534	25	479	571
C-D4.5-T0-A45	1166	67	1076	1268
C-D4.5-T1-A15	284	27	255	338
C-D4,5-T1-A30	1036	67	932	1157
C-D4,5-T1-A45	1853	34	1795	1907

Table 7. Perforation forces as a function of different nail angles and truncations.

Deformation

Nail	Average deformation (mm)	Standard deviation	Minimum deformation (mm)	Maximum deformation (mm)
C-D4.5-T0-A30	12.3	1.6	10.4	11.6
C-D4.5-T1-A30	14.8	0.8	13.6	15.9
C-D4.5-T2-A30	17.1	0.8	16.1	18.8
P-D4.5-T0-A30	10.6	0.4	10.0	11.4
P-D4.5-T1-A30	13.3	0.7	12.0	14.2
P-D4.5-T2-A30	16.0	0.6	15.3	17.3

Table 8. Insert deformations as a function of nails with different shapes and truncations.

Nail	Average deformation (mm)	Standard deviation	Minimum deformation (mm)	Maximum deformation (mm)
C-D4.5-T0-A15	8.3	0.6	6.9	9.2
C-D4.5-T0-A30	12.3	1.6	10.4	11.6
C-D4.5-T0-A45	15.0	0.9	13.7	13.1
C-D4.5-T1-A15	10.1	1.1	8.8	12.1
C-D4.5-T1-A30	14.8	0.8	13.6	15.9
C-D4.5-T1-A45	18.3	1.3	16.8	20.3

Table 9. Insert deformations as a function of nails with different angles and truncations.

Influence of nail diameter

Nail	Average force (N)	Standard deviation	Minimum force (N)	Maximum force (N)
P-D2.5-T0-A30	537	19	508	566
P-D3-T1-A30	737	27	694	790
P-D4.5-T2-A30	742	64	612	813

Table 10. Perforation forces as a function of pyramidal nail diameter.

Penetration velocity

Nail	Penetration velocity ($mm.min^{-1}$)	Average force (N)	Standard deviation	Minimum force (N)	Maximum force (N)
C-D4.5-T1-A30	10	1036	67	932	1157
	400	839	67	791	963
P-D4.5-T1-A30	10	742	64	612	813
	400	892	34	841	935

Table 11. Perforation forces for two different penetration velocities.

Sample clamping platen hole diameter

Perforation force

Nail	Sample clamping platen hole diameter (mm)	Average force (N)	Standard deviation	Minimum force (N)	Maximum force (N)
C-D4.5-T1-A30	12.5	1117	48	1037	1202
	25	1036	67	932	1157
	50	930	58	833	1000
P-D4.5-T1-A30	12.5	900	42	853	981
	25	742	64	612	813
	50	824	26	776	855

Table 12. Perforation forces for different sample clamping platen hole diameters.

Deformation

Nail	Sample clamping platen hole diameter (mm)	Average deformation (N)	Standard deviation	Minimum deformation (N)	Maximum deformation (N)
C-D4.5-T1-A30	12.5	9.8	0.8	11.7	11.7
	25	14.8	0.8	13.6	15.9
	50	20.0	1.3	18.2	22.3
P-D4.5-T1-A30	12.5	9.0	0.6	8.4	10.1
	25	13.3	0.7	12.0	14.2
	50	18.8	0.9	17.4	20.6

Table 13. Deformations as a function of sample clamping platen hole diameter.

Insert quality

Perforation force

Nail	Insert	Average force (N)	Standard deviation	Minimum force (N)	Maximum force (N)
C-D4.5-T1-A30	1	1036	67	932	1157
	2	1526	55	1441	1615
	3	1375	49	1270	1459
	4	1742	51	1625	1806
	5	1353	56	1248	1449
P-D4.5-T1-A30	1	742	64	612	813
	2	1581	60	1510	1695
	3	1230	105	1066	1405
	4	1472	56	1414	1578
	5	1074	68	952	1178
P-D3-T1-A30	1	737	27	694	790
	2	1206	87	1053	1302
	3	952	55	857	1022
	4	1139	54	1072	1216
	5	934	60	843	1025

Table 14. Perforation forces as a function of insert quality.

Deformation

Nail	Insert	Average deformation (mm)	Standard deviation	Minimum deformation (mm)	Maximum deformation (mm)
C-D4.5-T1-A30	1	14.8	0.8	13.6	15.9
	2	14.3	0.7	13.3	15.3
	3	14.9	0.5	14.1	15.8
	4	16.1	0.4	15.3	16.9
	5	17.3	0.8	15.9	18.7
P-D4.5-T1-A30	1	13.3	0.7	12	14.2
	2	13.2	0.4	12.6	13.9
	3	14.9	1.2	13.1	16.8
	4	15	0.8	14.1	16.8
	5	15.4	1.	13.6	17.2
P-D3-T1-A30	1	13.2	1.7	11.3	16.4
	2	13.4	1.3	12.3	15.6
	3	13.4	0.3	12.8	13.8
	4	13.9	0.4	13.2	14.3
	5	14.2	0.8	12.4	15.3

Table. 15. Deformations as a function of insert quality.