Pierce nut with dimension M6 and M8 in UHSS sheet

Johannes Gårdstam, Swerea KIMAB
johannes.gardstam@swerea.se
In an earlier work a new self-piercing nut and die geometry was designed with use of simulation models. The new nut was especially designed for use with high strength steel sheets. Cold-formed nuts have subsequently been manufactured and successful results were achieved when used in ultra high strength steel (UHSS) sheets.

Abstract

High strength steel sheets requires high stresses to deform. To reduce the setting forces, maximum mechanical locking at minimum sheet deformation was desirable. Thread damage is another problem that occurs with pierce nut in high strength steel. One reason for thread damage is the cutting sequence, where the strength and the thickness of the sheet highly influence the damage in the thread. The risk for thread damage can be reduced by changing the geometry of the nut or by increasing the strength of the nut material. [1]

In a previous work a simulation model was used to optimize the nut setting process with focus on use in high strength sheet steel. [1]

In this work cold formed pierce nuts, specially designed for high strength steels was used with successful results in UHSS sheets.

Cold formed M6 nuts exist for the sheet thickness range 1.0-2.0mm. Small modifications of the nut geometry could be done to optimise the nut for DP1000 and even harder sheet materials.

The production nut M6-Nut2, Figure 1, was tested at Volvo Cars. The nut was approved for use in production in combination with DP800 or softer sheets.

M8 is still in the iterative process to achieve a satisfactory geometry in combination with acceptable durability of the cold forming tools.

Pierce nut can be used in combination with roll-forming.
Table of Contents

1. Introduction ........................................................................................................ 7
2. Nut and sheet ....................................................................................................... 7
   2.1 M6-Nut2, 1.2-1.6mm.................................................................................... 8
   2.2 M6-Nut1, 0.6-1.2mm, prototype1.............................................................. 8
   2.3 M6-Nut3, 1.6-2.0mm, prototype1.............................................................. 9
   2.4 M8-Nut2, 1.2-1.6mm, prototype1.............................................................. 9
3. Setting equipment .............................................................................................. 10
   3.1 Setting process............................................................................................. 10
   3.2 Push-out ...................................................................................................... 10
4. Results .............................................................................................................. 11
   4.1 Laboratory results ....................................................................................... 11
      4.1.1 M6-Nut1 - 0.8mm DP600...................................................................... 11
      4.1.2 M6-Nut1 - 1.0mm DP1000................................................................. 12
      4.1.3 M6-Nut2 - 1.5mm DP1000................................................................. 13
      4.1.4 M6-Nut3 - 1.75mm TRIP700............................................................ 14
      4.1.5 M8-Nut2 - 1.5mm DP1000................................................................. 15
      4.1.6 Comparison of push-out strength for M6 nuts................................. 16
   4.2 In combination with roll-forming ................................................................ 17
   4.3 Industrial test of pierce nut in 1.5mm DP800............................................. 17
5. Conclusions ....................................................................................................... 18
6. Acknowledgment............................................................................................... 19
7. References ........................................................................................................ 19
Appendix ............................................................................................................... 19
1. Introduction

Screw fasteners are labour intensive and difficult to automate and therefore expensive in medium to high production runs. However, sometimes access to only one side is possible or unfastening of the joint may be needed during repair. This is possible with screws and nut, provided that the nut is mounted into the sheet or if the nut or screw is welded to the sheet. With screw fasteners it is also possible to combine an unlimited number of sheets of all kinds of materials and thicknesses. Pierce nut, Figure 2 to Figure 4, is a technique that punches the nut directly into and securely fixes the nut to the work piece in one operation. No pre-punched or pre-drilled holes are required. The pierce nut process is often integrated to the pressing line, where sheets will be formed to a beam, door, roof etc. and simultaneously as the sheet will be formed, the nut will be inserted into it. Pierce nut offers significant savings in time and costs over weld nuts that are installed outside the stamping line. The pierce nut requires a good installation to ensure optimal performance. Performance of a pierce nut can be divided into two sections. First the mechanical attachment between nut and sheet, e.g. torque and push-out resistance, this is called for the installation performance. Second, the mechanical strength of a final joint with the screw and the second sheet installed, e.g. the shear and peel strength of the final joints [2],[3].

During setting of pierce nuts there are other problems that occur when introducing new higher strength sheet materials. In industrial nut setting operations it was found that the thread of the pierce nut was damaged and scatter in push-out strength were obtained when the pierce nut was set in a sheet of high strength steel [1]. In this work a new cold formed nut was evaluated when used in the UHSS steel.

2. Nut and sheet

Four new nuts, special developed for use in HSS sheet have been evaluated in nut setting trials in UHSS sheet. Three of the nuts have dimension M6 and specified for different sheet thickness in the range 0.6-2.0mm. One of the nuts is a M8 nut specified for 1.2-1.6mm sheet thickness. Section of the nuts can be observed in section 2.2 to 2.4. The sheet used in this work can be observed in Table 1.

<table>
<thead>
<tr>
<th>Thickness [mm]</th>
<th>Steel grade</th>
<th>Rp0.2 [MPa]</th>
<th>Rm [MPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.8</td>
<td>DP600</td>
<td>350-450</td>
<td>600-700</td>
</tr>
<tr>
<td>1.0</td>
<td>DP1000</td>
<td>700-950</td>
<td>1000-1200</td>
</tr>
<tr>
<td>1.5</td>
<td>DP1000</td>
<td>800</td>
<td>1091</td>
</tr>
<tr>
<td>1.75</td>
<td>TRIP700</td>
<td>487</td>
<td>706</td>
</tr>
</tbody>
</table>
2.1 M6-Nut2, 1.2-1.6mm
The M6 nut for sheet thickness 1.2-1.6mm was the first nut developed for HSS. A simulation plot from a process simulation can be observed in Figure 5. After several iterations during the cold forming manufacturing, a final shape of a M6 nut was achieved. The final shape of a cold formed M6-Nut2 can be seen in Figure 6. A section of the final M6-Nut2 can be seen in Figure 7.

![Simulation of the nut setting process from the development process [1].](image)

![Cold formed M6-Nut2 from Bulten.](image)

Figure 5. Simulation of the nut setting process from the development process [1].

Figure 6. Cold formed M6-Nut2 from Bulten.

![Section of a M6-Nut2.](image)

Figure 7. Section of a M6-Nut2.

2.2 M6-Nut1, 0.6-1.2mm, prototype1
The dimensions of the M6-Nut1 are almost similar to the M6-Nut2, except for the shorter neck that cuts and lock the sheet. The angle of the neck has been increased to achieve equal diameter of the neck, D in Figure 8, which is required since the nut is used in combination with the same die as the nuts that are made for thicker sheets.

![Section of a M6-Nut1.](image)

Figure 8. Section of a M6-Nut1.
2.3 M6-Nut3, 1.6-2.0mm, prototype1
The dimensions of the M6-Nut3 are almost similar to the M6-Nut2, except for the longer neck that cuts and lock the sheet, see Figure 9. The angle of the neck has been reduced to achieve equal diameter of the neck which is required since the nut is used with the same die as the nuts made for thinner sheets.

![Figure 9. Section of a M6-Nut3.](image)

2.4 M8-Nut2, 1.2-1.6mm, prototype1
The M8 nut for sheet thickness 1.2-1.6mm was radial expanded from the M6 dimensions, see revolved simulation plot of an M8-Nut2 in Figure 10. The M6 nut required several iterations with new cold forming tools to come up with a successful nut geometry and also a durability of the cold forming tools that was satisfactory. For the M8-Nut2 prototype1, it is still required with small modifications for optimal nut geometry. The durability of the cold forming tools must also be improved before mass production of M8 nuts. The shape of a cold formed non coated M8-Nut2 prototype1 can be seen in Figure 11. A section of the M8-Nut2 prototype1 can be seen in Figure 12.

![Figure 10. Revolved axi-symmetric results from M8-Nut2.](image)

![Figure 11. Cold formed M8-Nut2, prototype 1, from Bulten.](image)

![Figure 12. Section of a cold formed M8-Nut2 prototype 1.](image)
3. Setting equipment

3.1 Setting process
The nut setting process was performed in hydraulic MTS equipment with a capacity of 100 kN. To stabilise the process and perform a controlled nut setting process a four-column stand was used, Figure 13. The four-column stand was equipped with a punch, which operates centric in a slide bearing with minimal tolerances to avoid tilting. At the end of the punch there is a hole and a rubber gasket to centre the nut, in the bottom of that hole there is a thread for montage of other tools, Figure 14. At the lower part of the four-column stand a socket is located and the socket has the opportunity to move 0-1.0 mm in one direction, which can be used to create controlled off centring in relation to the punch.

A die was mounted in the socket and a nut was placed in the punch. The setting process consists of three steps. First a speed controlled step when the nut feeds into the sheet with 2mm/s until the sheet was cut. Secondly a load controlled step, 200 kN/min until desired load level was achieved. Finally the punch returns with a load controlled step –300 kN/min until the joint was released. The displacement and the current force acting on the nut were stored during the nut setting process.

3.2 Push-out
The joint was tested in push-out resistance. The same equipment is used as in the nut setting process. However, the die is replaced with a support that has a hole for the nut. The hole has a diameter that is 1.0mm larger than the nut diameter. A push-out tool was mounted in the punch to push-out the nut. As in the setting process, the displacement and the force acting on the nut were stored during push-out.
4. Results

Results are divided into three sections. In section 4.1, laboratory results are presented for several nut and HSS- or UHSS-sheet combinations. In section 4.2, a short presentation of the results with pierce nut M6-Nut2 in combination with roll-forming and 1.5mm DP1000 is presented. In section 4.3, the result report from the evaluations of the M6-Nut2 for industrial implementations at Volvo Cars is presented.

4.1 Laboratory results

Nut setting trials have been performed and push-out resistances has been evaluated at Swerea KIMAB, with the setting equipment seen in section 3. The same die was used in all laboratory trials, and the die was not optimised for this set-up. Consequently, further improvements regarding the setting process are possible.

4.1.1 M6-Nut1 - 0.8mm DP600

A section of a joint that consist of a M6-Nut1 and a 0.8mm DP600 can be seen in Figure 16. As seen in the figure, the distance A must be less than the sheet thickness, otherwise the objects that will be mounted to the pierce nut will be pressed towards the nut rather than to the sheet. In this case the distance A is 1.0mm, consequently minimum sheet thickness for the M6-Nut1 should be 1.0mm. However, this is a prototype nut and modifications of the nut geometry are still possible. The setting force was in this case 30 kN.

![Figure 16. Section of a M6-Nut1, mounted to a 0.8mm DP600 with a force of 30kN.](image_url)

Even though the setting forces for the experimental joint was not optimised to achieve maximum push-out strength, the maximum push-out strength was 1.3 kN, seen in Figure 17. The push-out was aborted at a displacement of 1.1mm, consequently the M6-Nut1 was not totally pushed-out and the total push-out energy could not be evaluated.

![Figure 17. Push-out force and displacement for a M6-nut1 mounted to a 0.8mm DP600.](image_url)
4.1.2 M6-Nut1 - 1.0mm DP1000
A section of a joint that consist of a M6-Nut1 and a 1.0mm DP1000 can be seen in Figure 18. The setting force was in this case 50 kN. An optimised die, increased setting force or reduced size of the ring B should perform even more mechanical locking and reduced risk for remaining sheet pieces.

![Section of a M6-Nut1, mounted to a 1.0mm DP1000 with a force of 50kN.](image)

Even though the setting forces for the experimental joint was not optimised to achieve maximum push-out strength, the maximum push-out strength was 3.2 kN, seen in Figure 19. The push-out was aborted at a displacement of 0.7mm, consequently the M6-Nut1 was not totally pushed-out and the total push-out energy could not be evaluated.

![Push-out force and displacement for a M6-nut1 mounted to a 1.0mm DP1000.](image)
4.1.3 M6-Nut2 - 1.5mm DP1000

A section of a joint that consist of a M6-Nut2 and a 1.5mm DP1000 can be seen in Figure 20. The setting force was in this case 70 kN. As seen to the left in Figure 20, the section was made through a torsion locking mark, C. The effect of the ring that penetrates the sheet and force material to the centre, into the locking volume, can be observed by comparing left and right side of Figure 20. An optimised die, increased setting force or reduced size of the ring should perform even more mechanical locking and reduced risk for remaining sheet piece. However, this is a production nut, optimised for DP600 and DP800 steels, which are more common in the industry these days. But, with small modifications this nut will probably perform very well with DP1000 and even harder sheet materials as well.

![Figure 20. Section of a M6-Nut2, mounted to a 1.5mm DP1000 with a force of 70kN. The section goes through a torsion locking mark at the left side in the picture.](image)

Even though the setting forces for the experimental joint was not optimised to achieve maximum push-out strength, the maximum push-out strength was 4.6 kN, seen in Figure 21.

![Figure 21. Push-out force and displacement for a M6-nut2 mounted to a 1.5mm DP1000.](image)
4.1.4 M6-Nut3 - 1.75mm TRIP700
A section of a joint that consist of a M6-Nut3 and a 1.75mm TRIP700 can be seen in Figure 22. The setting force was in this case 70 kN and the mechanical locking is satisfactory, especially at the right side of the section.

Even though the setting forces for the experimental joint was not optimised to achieve maximum push-out strength, the maximum push-out strength was 7.4 kN, seen in Figure 23. The push-out was aborted at a displacement of 1.6mm, consequently the M6-Nut3 was not totally pushed out and the total push-out energy could not be evaluated.

![Figure 22. Section of a M6-Nut3, mounted to a 1.75mm TRIP700 with a force of 70kN.](image)

![Figure 23. Push-out force and displacement for a M6-nut3 mounted to a 1.75mm TRIP700.](image)
4.1.5 M8-Nut2 - 1.5mm DP1000

A section of a joint between a M8-Nut2 prototype and a 1.5mm DP1000 can be seen in Figure 24. The setting force was in this case 80 kN. Suggested geometrical modifications seen in Figure 25 should perform even more mechanical locking, reduced setting force and reduced risk for remaining sheet piece.

![Figure 24. Section of a M8-Nut2 prototype 1, mounted to a 1.5mm DP1000 with a force of 80kN.](image1)

![Figure 25. Suggested improvements for coming M8-nut2 manufacturing.](image2)

Compared to the M6 nut the M8 nut perform reduced push-out strength. This is a consequence of the non optimised M8 nut. With an optimised M8 nut the push-out strength should be higher than the push-out strength of the M6 nut, as a consequence of longer circumference of the mechanical locking.

![1.5mm DP1000](image3)

![Figure 26. Comparison of the push-out force for a M6-Nut2 and a M8-Nut2 prototype1 in 1.5mm DP1000.](image4)

The M8-Nut2 prototype1 was tested at several sheet strength (1.5mm) and setting forces, see Table 2 and Table 3. The thread was not damaged in any case but a remaining sheet piece was achieved when used in combination with MS1200. However, the push-out strength could probably be improved by relatively small modifications of the nut geometry.
Required setting force could also be reduced by the geometry modifications suggested in Figure 25.

<table>
<thead>
<tr>
<th>Table 2. Classification of joints.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thread ok!</td>
</tr>
<tr>
<td>Thread damaged!</td>
</tr>
<tr>
<td>Thread ok, sheet piece loose but remain with the joint.</td>
</tr>
<tr>
<td>Thread ok, sheet piece remains with the joint.</td>
</tr>
<tr>
<td>Thread damaged and sheet piece remains with the joint.</td>
</tr>
<tr>
<td>Not tested!</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 3. Push-out strength and classification of joints for different sheet (1.5mm) and M8-Nut2 prototype 1.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>50 kN</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>60 kN</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>70 kN</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>80 kN</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

4.1.6 Comparison of push-out strength for M6 nuts

Comparison of the push-out strength for the M6 nuts specified for different sheet thicknesses can be observed in Figure 27. M6-Nut1 and M6-Nut3 are prototype nuts and M6-Nut2 is a production nut. The push-out strength seems to be correlated to the sheet thickness. The elongation during push-out is at least the length of the sheet thickness. Consequently, a large amount of energy is required to loosen the nuts completely.

Figure 27. Comparison of push-out forces for different nuts mounted in different sheet strengths and sheet thicknesses.
4.2 In combination with roll-forming
Trials with pierce nuts in combination with roll-forming have been evaluated with successful results, see Figure 28. The nuts were mounted into the 1.5mm DP1000 sheet before the sheet was formed. The nuts will then follow the sheet through the roll-forming line, where tracks have been milled into the roll-forming rolls at the locations for the nuts. Roll-forming can create closed profile, see Figure 29, and pierce nut can be used in combination with roll-forming. Consequently, closed profiles with mounted nuts inside the profile ready for subsequent assembly from the outside of the profile can be created.

![Figure 28. M6 Pierce nut mounted in a roll-formed profile. The nuts were mounted before the sheet was formed.](image)

![Figure 29. With roll-forming it is possible to create a closed profile.](image)

4.3 Industrial test of pierce nut in 1.5mm DP800
See Appendix for test report from Volvo IUC.
5. Conclusions

- Pierce nut that was specially designed for high strength steel can also be used in UHSS sheets.

- Cold formed M6 nuts for use in UHSS sheets exist for the sheet thickness range 1.0-2.0mm. Small modifications of the nut geometry could be done to optimise the nut for DP1000 and even harder sheet materials.

- The production nut M6-Nut2 was tested at Volvo Cars. The nut was approved for use in combination with DP800 or softer sheets.

- M8 is still in the iterative process to achieve a satisfactory cold formed geometry in combination with acceptable durability of the cold forming tools.

- Pierce nut can be used in combination with roll-forming.
6. Acknowledgment

This work was sponsored by VINNOVA within the project ”Lättviktprodukter i ultrahöghållfast stål, Lätt-UHS, Dnr 2006-00561, which is gratefully acknowledged.

The author is grateful for the contributions to the project from Zoltan Pap at Strömsholmen AB and Rolf Carlsson at Bulten AB.

7. References


Appendix