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Design of a snap connector to connect panel elements

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Abstract:*Design of a snap connector to connect panel elements*. The aim of this study was to design, manufacture and verify the tensile strength of a prototype snap connector to be used to connect panel elements. Firstly, analyses were conducted on solutions of commercially available designs for connectors invisible from the cabinet's outside and those with minimized visibility. While searching for the best concept of connector design, three proposals were prepared, of which – after thorough analysis of design – one concept was selected. In the next step, the adopted solution was improved so that the connector met the previously formulated design requirements. In the course of further analyses, the causes and effects of failure were verified in order to limit or eliminate potential defects. In the next stage of the study, numerical calculations were conducted for the nut and the connector, concerning tensile strength, using the Autodesk Simulation Multiphysics program.
After a prototype connector was manufactured, tensile strength tests were conducted on the connector using a strength testing machine. Experiments verified the correctness of the developed design in terms of geometry and the physico-mechanical properties of materials of individual elements, and resulted in possible changes proposed in the design of the final connector product.

Keywords: connecting elements, snap connector, numerical calculations

INTRODUCTION

At present, the furniture manufacturing industry accounts for approx. 2% GDP of the Polish market and comprises approx. 24 thousand enterprises. Thanks to such a considerable potential, in 2012 Poland ranked 4th in the European Union in terms of the value of furniture production at 6.9 billion Euro (Adamowicz and Wiktorski2013). Due to the high volume of furniture production, there is a great demand for all types of furniture hardware, including also connectors. Currently, many types of connectors used in furniture manufacturing are commercially available, while in terms of connections we may distinguish three main types: with mechanical connectors, fittings and adhesive inserts. The connections with mechanical connectors may be further subdivided into removable and permanent. The requirements imposed on connectors by the present day market are very high. They are expected to be reliable, very accurately and precisely manufactured, to have high strength parameters and a simple design. Moreover, final users of furniture consider the esthetic value of products to be of great importance. Thus we observe a growing trend to minimize the conspicuity of connectors. Many producers of furniture hardware worldwide strive to design connectors that would attract as little consumer attention as possible. Such R&D work resulted in the design of connectors for elements made from wood and wood-based materials such as Rafix, Tab 18 or Rasant Tab by Häfele, very popular Rastex connectors by Hettich or a very discrete Rostro connector by EffegiBrevetti. All these hardware elements combine functional properties (removable connectors) and esthetic value (minimized visibility from the cabinet's outside). However, complete invisibility of the connectors – with some exceptions – may be provided only on condition that the connectors are permanent, i.e. devoid of the functionality of multiple use. At present, an exception in this respect is provided only by solutions based on the use of magnetic field, which considerably increases production costs of connector elements and is the primary cause for the limited interest in this design among furniture manufacturers.

Permanent connectors constitute a relatively small group of designs. They include, first of all, snap connectors. Relatively popular products available on the market are e.g. theTenso P-14 snap connector (Fig. 1) by Lamello, the MOD-EEZ self-locking fastener (Fig. 2) and the Titusonic special rivets (Fig. 3) by Titus.

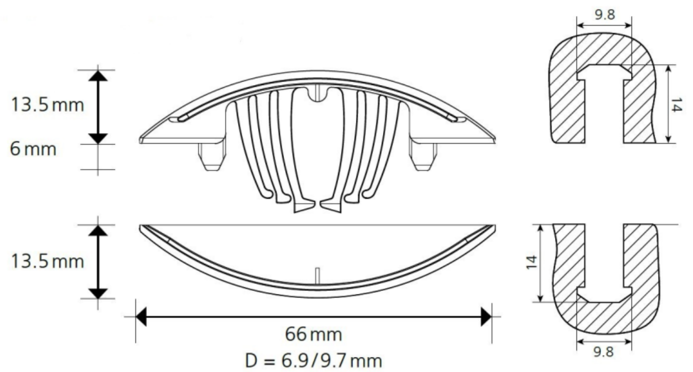

Figure 1. Tenso P-14 connector (Source: Catalogue Lamello 2019)

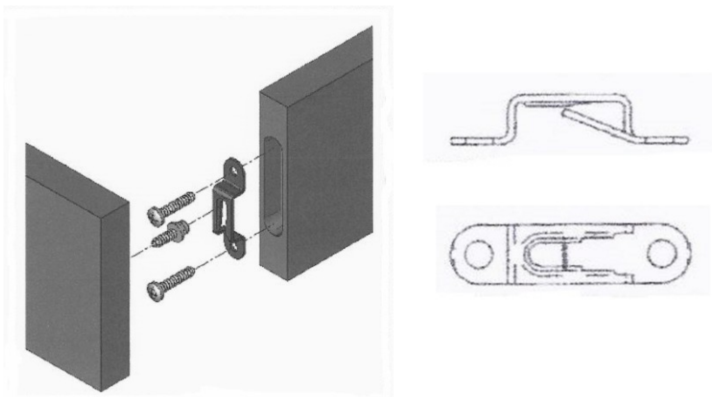

Figure 2. MOD-EEZ connector: a – diagram of connection, b – drawing of a connector (Source: Catalogue MOD-EEZ2019)

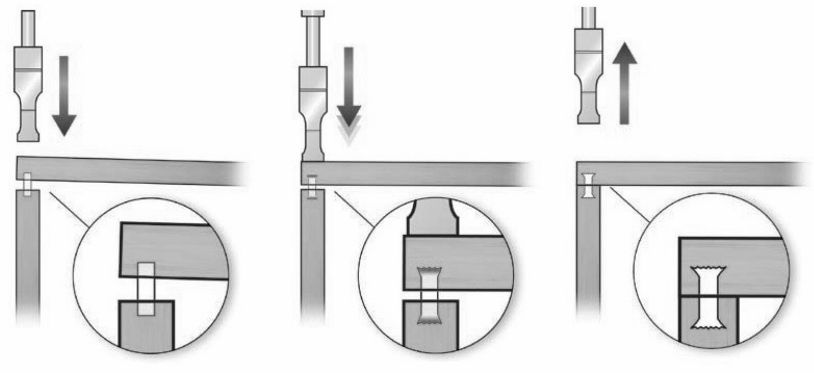

Figure 3. A diagram of connection according to the WoodWelding method (Catalogue Titus 2019)

Although completely invisible after the elements are joined, these connectors are burdened with certain drawbacks. The primary disadvantages of these solutions include relatively large dimensions of connector elements, a complex design, and the need to use specialist tools when machining joined elements. Another drawback is also connected with the use of plastics, which due to their contents of released chemical compounds prevent disposal by incineration of furniture containing these connectors.

Thus, the primary aim of this study was to design and produce a prototype snap connector for joining panel elements that would have the following characteristics:
– simple design,
– small dimensions,
– use of materials allowing disposal by incineration,
– no need to use specialist tools during machining and assembly.

The result of this study important from the point of view of pure science was to determine the tensile strength of the prototype connector. The objective important for practice was connected with the verification of the theoretical solution for the new connector design by FEM numerical analysis, and preparation of technical documentation.

MATERIALS

The authors assumed that the designed connector should be suited for various applications - not only in furniture, but also in other products made from wood and wood-based materials. For this reason, the following limitations were assumed for the designed connector:
– minimum thickness of joined elements: 16 mm,
– maximum recess depth for the connectorelement: 12 mm,
– assembly of the connector with no specialist tools required,
– no plastics used in theconnector,
– connector invisible from the outside.

The design problem was solved based on a review of commercially available connectors and an analysis of various concepts for design solutions of the prototype connector.

The optimal solution to the design problem was selected from among several analyzed design concepts. The selection criteria included simplicity of design, metal as the structural material and small dimensions.

It was assumed that modification will be possible thanks to the improvement of the concept so that it would meet the previously stated requirements. The specially designed snap connector, meeting the specified assumptions, is composed of four elements: a double-threaded joint, a single-threaded joint with a stop, a nut and a screw (Fig. 4).

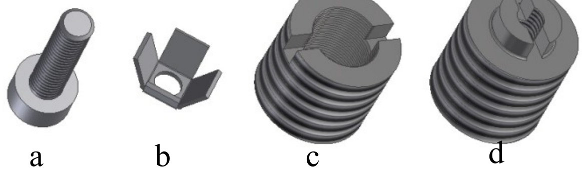

Figure 4. Elements of the snap connector. a – the M3 screw, b – the nut, c –the single-threaded joint with a stop, d – the double-threaded joint

A model of the selected design for the snap connector is presented in Fig. 5.In the double-threaded joint and in the single-threaded joint with a stop,on the outer cylinder surface, a metric thread M10 with apitchof 1.5 mm was used. The single-threaded joint with a stop has special ridges with a pitch of 0.3 mm to block thenut.The double-threaded joint has a seat for the metric M3 screw with a pitch of 0.5 mm. The M3 screw is standardized according to the PN-EN ISO 4762 (2006) specifications, which makes it readily accessible.

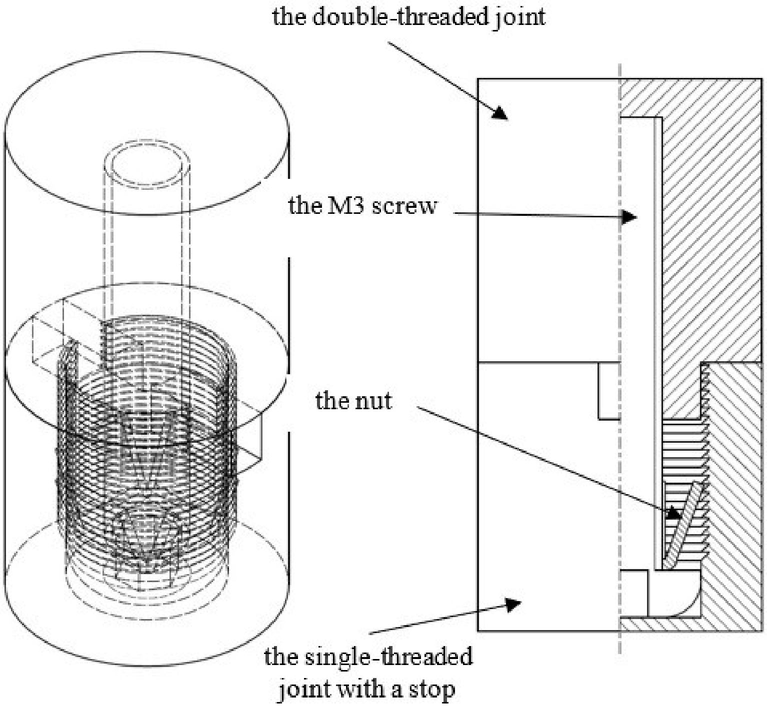

Figure 5. A model of the selected connector design

The screw has a capstan head with a hexagonal seat of the following dimensions: height k = 3 mm and diameter d_k = 5.5 mm. The depth of thread in screw b (Fig. 6) corresponds to the length of the pin l = 12 mm. A specially bent square nut, 0.4 mm thick, is screwed on the M3 pin having a thread with a 0.5 mm pitch. Dimensions of the M3 screw selected for the connector are given in Fig. 6.

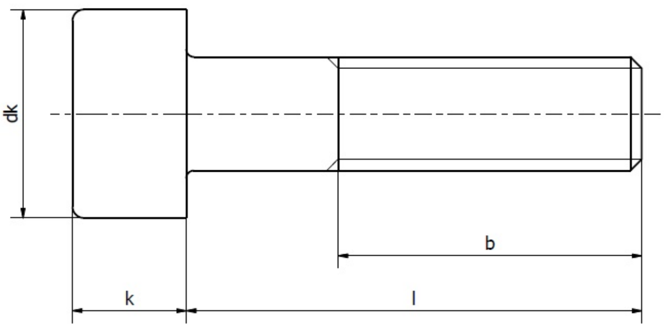

Figure 6. Dimensions of screws with flat, oval or round capstan heads used in the connector: dk = 3.5 – 5.6 mm, l = 12 mm, b = 12 mm, k = 3 mm

The difference in the height of the double-threaded joint and the single-threaded joint with a stop amounts to 0.5 mm. The difference in height was intentional, it was introduced to provide clearance to ensure proper matching of joints.

When starting the assembly in the joinedelements, seats need to be made of 10 mm in depth and 8.5 mm in diameter. The diagram of assembly for the snap connector is presented in Fig. 7.

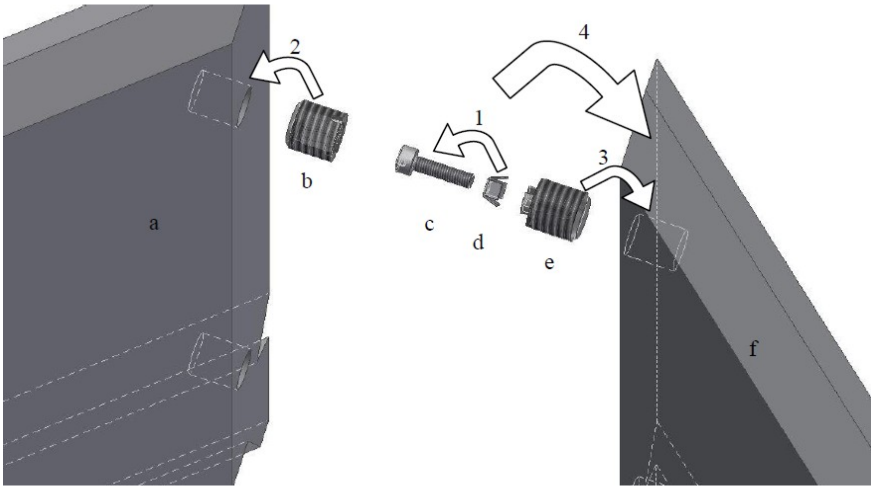

Figure 7. A diagram of assembly of the snap connector: a – element 1, b – single-threaded joint with a stop, c – screw, d – nut, e – double-threaded joint, f – element 2

The assembly operation needs to be performed following the successive steps:

- step 1 – nut (d) is screwed on the M3 screw (c),
- step 2 – the single-threaded joint with a stop (b) is screwed into the seat of the first element (a),
- step 3 – the double-threaded joint (e) is screwed into the seat of the second element (f),
- step 4 – the M3 screw (c) with the nut (d) is screwed into the double-threaded joint (e).

At the moment of applyingadequate force, the connector snaps shut, as a result of the nut being blocked by the respective ridge in the single-threaded joint with a stop.

According to the method proposed by Hamrol and Mantura(2012), in order to obtain information on the strengths and weaknesses of a product,the Failure Mode and Effect Analysis (FMEA)may be conducted already at the stage of preliminary design work on a new connector. This analysis makes it possible to verify the potential of occurrence of a given failure in the new product, and for this reason it is frequently performed at the first stage of designing novel products, before they reach the production stage. Thanks to this analysis, weaknesses of the product may be prevented, limited or eliminated. When designing the connector, FMEA was conducted as follows:

- potential for failure in the final product was analyzed,
- it was assessed according to the scale of importance, detectability and incidence rate of a given failure type,
- the priority score was calculated for individual failures.

In FMEA, a given failure of the product is assessed (Hamrol and Mantura2012) by assigning to it the so-called priority score. The assessment for the calculation of the priority score is conducted using three criteria:

- importance of the failure – Z, where 1 means that the failure is of no importance, while 10 denotes great importance,
- detectability of the failure – W, where 1 means that the detection of the failure is very easy and 10 means that the failure may not be detected,
- possibility of the failure – R, where 1 means that the occurrence of the failure is improbable and 10 denotes inevitability of the failure.

The letter P denotes the priority score informing on the importance of a given failure type, calculated according to the following formula (1):

$$P = Z * W * R \quad (1)$$

At the design phase of a new product, an important stage consists in performing numerical calculations using the Finite Elements Method (FEM). It makes it possible to exclude or improve defective elements already at the design stage. The Autodesk Simulation Multiphysics environment was used for FEM calculations.

During numerical calculations, the recorded values were compared to the respective strength grades of screws used in dynamometry (in accordance with the standardPN-EN ISO 898-1: 2013).In this manner, the connector was evaluated, so that it met requirements greater than or equivalent to grade 6.8.

In the first stage of the study,a decision was made to conduct numerical calculations of the nut element. In order to obtain information whether the material may withstand the process of nut forming,the bending of a steel sheet element was simulated in the test. A model of 0.5 mm in thickness had a M3 tapped hole with a pitch of 0.5 mm. The examined element was placed on a support so that the action of forces resembled the real conditionsas closely as possible. The following settings were adopted in the program:

– type ofelement: brick,
– mesh type: bricks and tetrahedra,
– mesh density of the nut: 25% ,
– mesh density of the support: 190%,
– mesh size for the nut: 0.3 mm,
– mesh size for the support: 1 mm,
– assumed contact: bonded (between the nut and support),
– nut material: AISI 1005 Steel,
– support material: AISI Type 304 Stainlees Steel.

In order to provide complete restraint of the model, the hole was assigned nodes preventing translation in the X, Y and Z axes. At each shoulder end of the nut element, a constant load of 10 N was exerted vertically downwards, following the Y axis (Fig. 8).

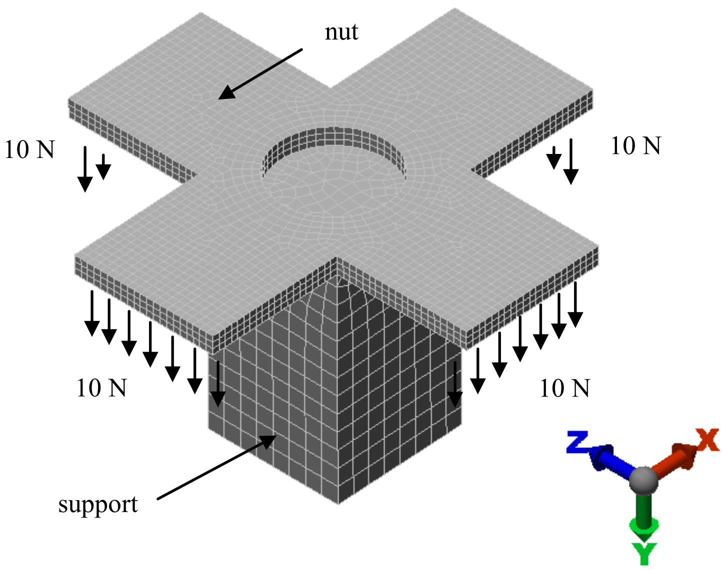

Figure 8. A mesh model of the nut

In the next stage, stretching was simulated for the whole connector. When preparing a simplified model for numerical calculations,no bevelling of edges was applied in the double-threaded joint, the single-threaded joint with a stop or the screw. The bolt head was also simplified thanks to changes in its shape and elimination of rounded edges. Due to the axes of symmetry found in the connector, in order to shorten the numerical calculations, the analyses were conducted only on the model of a half of the connector.

The following settings were adopted when preparing the model for calculations:
- type ofelement: brick,
- mesh type: bricks and tetrahedra,
- mesh density of thedouble-threaded joint: 60 %,
- mesh density of thesingle-threaded joint with a stop: 45 %,
- mesh density of the nut: 45 %,
- mesh density of the screw: 60 %,
- mesh size for the double-threaded joint: 3 mm,
- mesh size for the single-threaded joint with a stop: 0.3 mm,
- mesh size for the nut: 0.3 mm,
- mesh size for the screw: 3 mm,
- contact at the interface of the elements: surface contact (coefficient of friction for steel on steel: 0.15),
- material for all elements: AISI 1005 Steel.

Elements were assigned the following movement constraints:
- a constraint was put on translation towards the X, Y and Z axes for the screw and the double-threaded joint,
- a constraint was put on translation towards the X axis for the nut,
- a constraint was put on translation in one plane: X, Z for the single-threaded joint with a stop.

Stretching of the connector was simulated in the course of the analyses. For this purpose,a surface load of 15 N directed vertically, opposite to the direction of the Y axis, was placed on the bottom of the seat in the single-threaded joint with a stop (Fig. 9).

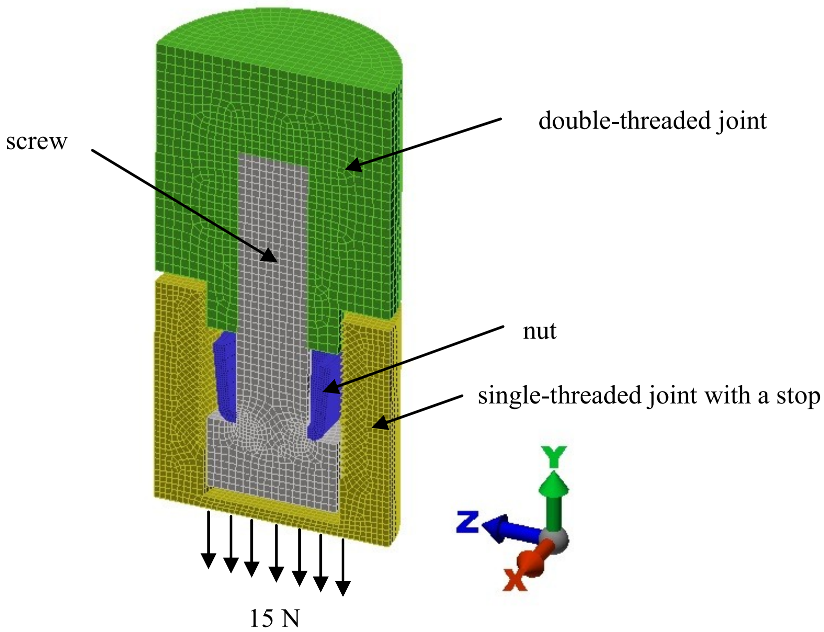

Figure 9. A mesh model of the connector

Prior to tensile strength testing of the connector, it was necessary to manufacture a prototype connector. A small batch of prototype elements was commissioned. A standardized screw was purchased in a single-line store. Table 1 presents material specifications. The double-threaded joint, the single-threaded joint with a stop and the screw were made to meet the requirements of the previously assumed quality grade (Table 1).

Table 1. Material specifications for connector elements

Name of element	Material	Tensile strength R_m[MPa]	Yield point R_e [MPa]
double-threaded joint	Structural carbon steel C45	600-800	355-430
single-threaded joint with a stop			
nut	Galvanized steel DX51D+Z275	270-500	140-300
screw	Galvanized steel grade 8.8	800	640

Due to the limited time of testing, the nut was made ofa lower grade material (grade 5.6) than it had been initially assumed (at least grade 6.8). The elements of the prototype connector are presented in Fig. 10.

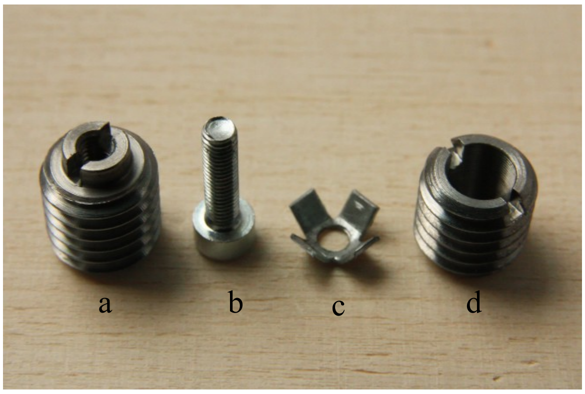

Figure 10. A prototype snap connector: a – double-threaded joint, b – M3 screw, c – nut, d – single-threaded joint with a stop

The tensile strength testing of the connector was conducted on a batch of 10 connectors using a Zwick 1445 strength testing machine. Prior to the tests, the connectors were assembled (snapped shut). During the tests, the connectors were mounted in the special clamps of the testing machine, parallel to the cross-bar motion axis. The connector was subjected to the tensile strength test at 10 mm/min. After the test was completed, the values of forces causing failure (uncoupling) of the connector were analyzed and the inflicted damage was assessed visually.

RESULTS

Table 2 presents FMEA results, which gives a list of potential defects of the product together with the proposals for their elimination or limitation.Obtained priority scores constitute the basis for the introduction of changes, potentially leading to the improvement of the final product. According to FMEA, the nut is the element most susceptible to failure. The highest priority score was assigned to nut bending, for which it was 144. We proposed to eliminate the problem by using a different material or changingthe nut shape. Another defect in this element was connected with the potential thread damage. This failure receiveda priority score of 96.

Table 2. FMEA for the designed snap connector

Item	Defect	Proposal for elimination	Z	W	R	P
1	Nut bending	Use of a different material /change of nut shape	6	6	4	144
2	Connector off-size	Increasing the scale of connector	7	4	4	112
3	Thread damage in the nut	Use of a different material / increasing nut thickness	8	3	4	96
4	Nut cracking	Use of a different material	9	5	2	90
5	Insufficient pressure of double-threaded joint to single-threaded joint with a stop	Reduction of pitch in stop ridges	8	2	5	80
6	Chipping of stop ridges	Change in stop ridge shape	8	4	2	64
7	Screw thread damage	Use of a different material	8	3	2	48
8	Thread damage in double-threaded joint	Use of a different material	8	3	2	48
9	Axis displacement of double-threaded joint and the joint with a stop	Reduction of clearance between elements	4	3	3	36

Numerical calculations facilitated an analysis of distribution of reduced stresses appearing in the elements of the tested connector under the working load.When analyzing the distribution of stresses in the element, it needs to be stated that stresses accumulate mainly in the corners and around the nut (Fig. 11).

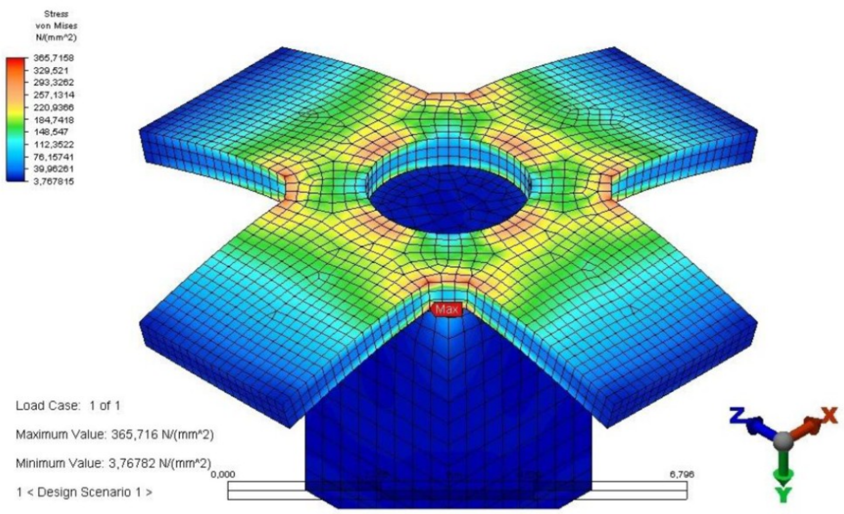

Figure 11. Distribution and values of reduced stresses in the nut

However, the Huber-Mises maximum reduced stresses (approx. 340 MPa) do not exceed admissible values for the used material. This result is satisfactory and suggests no damage during machining of the nut element in the process of steel sheet bending.

When analyzing the distribution of stresses, it needs to be stated that stresses accumulate mainly in the contact zones of mated elements: the nut and the stop. Nut corners are sites at the greatest risk of damage. Analysis of results showed that the greatest stresses were formed at the contact zone of the nut with the ridges of the single-threaded joint stop (Fig. 12), i.e. at its corners, and they amounted to approx. 580 MPa. On the surface of stop ridges, these stresses were much smaller, i.e. maximum approx. 230 MPa.

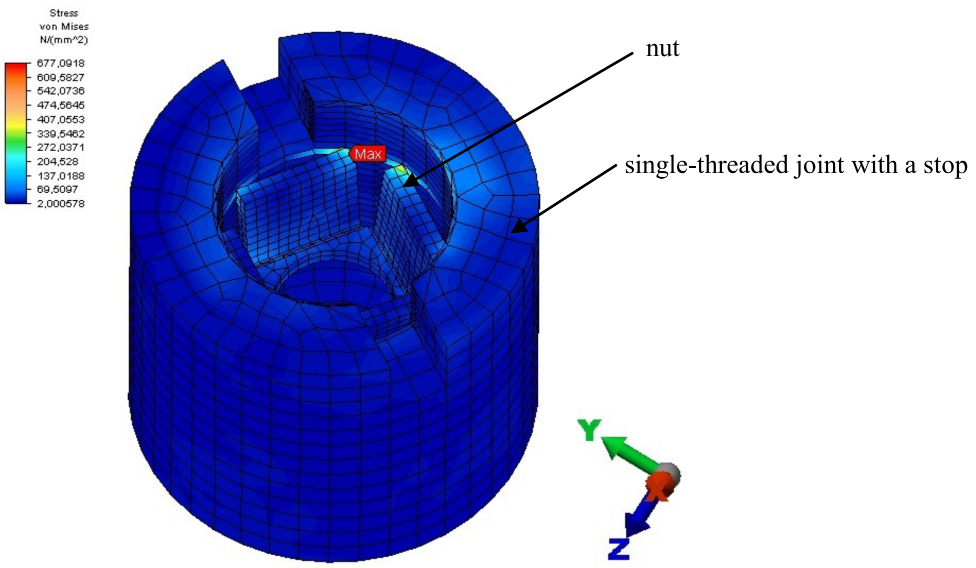

Figure 12. Distribution and values of reduced stresses on the surface of the nut and the single-threaded joint with a stop

The analysis of the specifications of the PN-EN ISO 898-1 (2013) standard and the recorded testing results indicates that the nut would not meet the requirements of the minimal assumed quality grade 6.8. For this reason, the recommendation should be to have it made in strength grade 8.8. The other elements of the connector (the double-threaded joint, the single-threaded joint with a stop, the screw) should easily meet the assumed requirements.

The strength criterion for the snap connector subjected to tensile testing was the value of force that would cause decoupling of the joined (snapped shut) connector.The results of tensile strength testing for the connector are presented in Fig. 13.

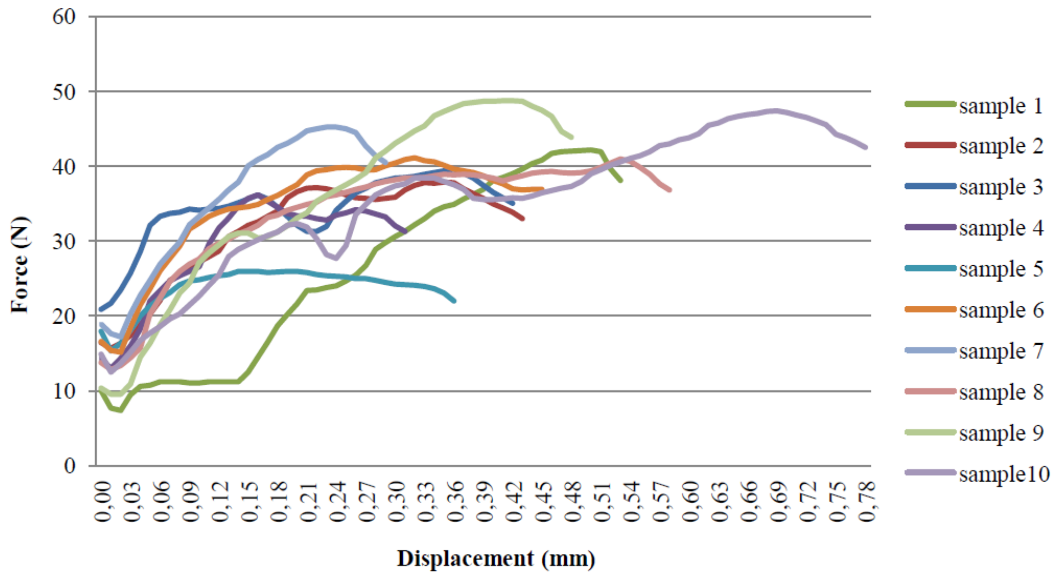

Figure 13. Tensile strength testing for the connector

Immediately after the onset of the test and exertion of load, a slight decrease in force was recorded, probably due to the so-called meshing of all nut shoulders. In the case of sample 5, a relatively low value of force was obtained due to the delicate bending of the nut element at the moment the connector elements snapped shut.

Figure 14 presents the mean value of the recorded results with their scatter. Since some of the connectors failed even before the displacement of 0.76 mm, the presented results fall within the range of 0-0.58 mm. Maximum averaged force causing no displacement of connector elements was approx. 15 N. The greatest discrepancies in relation to the mean value were observed at displacements ranging from 0.09 to 0.18 mm, with a mean of 6.96 N. The standard deviation for all tests was 6.67 N. It was calculated based on the mean for all the maximum values that caused a complete failure of the tested connector, which amounted to 40.3 N.

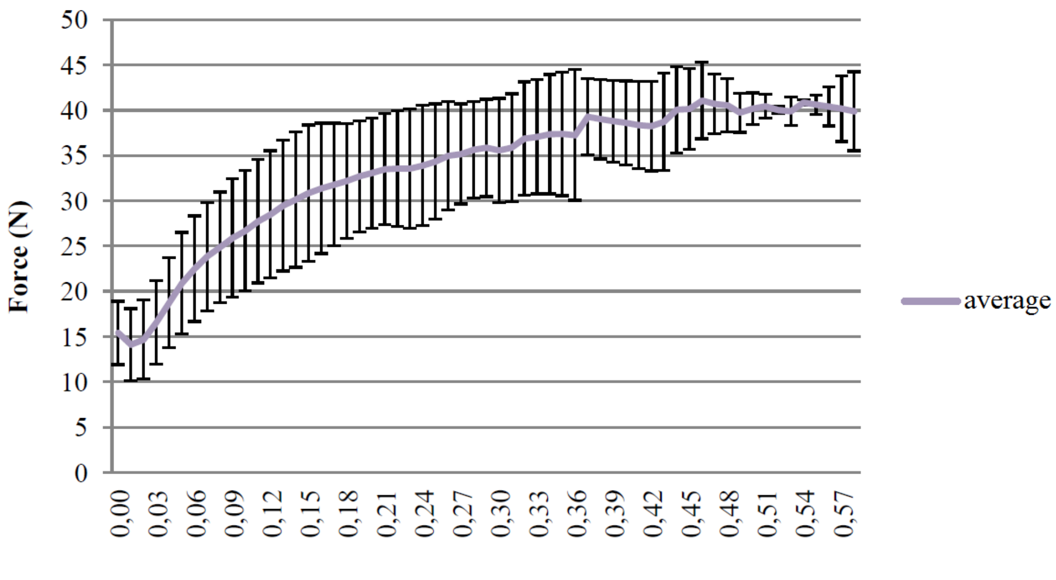

Figure 14. Mean value and standard deviation of tested specimens

Upon thorough examination of uncoupled connectors, a truncation of nut shoulders was observed in each test (Fig. 15).

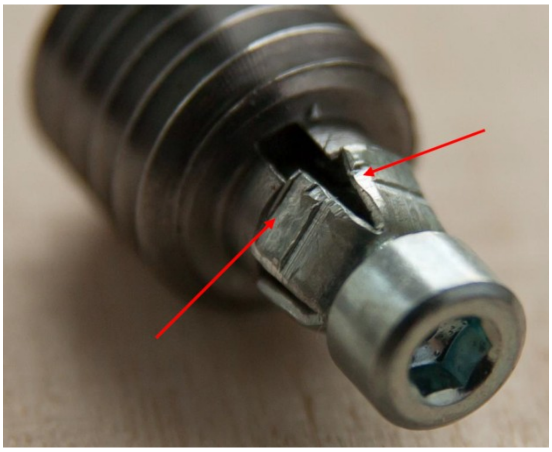

Figure 15. Damage on nut edges

This damage was caused by the nut rubbing againstthe stop ridges. No damage was found in single-threaded joints with stops, which may indicate better properties of the material of which these elements were made.

CONCLUSIONS

Based on the collected information, the conducted analyses and tests, the following conclusions were formulated:

1. A review of the existing design solutions of removable and permanent connectors together withthe adopted assumptions made it possible to design and produce a prototype of a new snap connector.
2. The best possible design solution for the connector was selected thanks to ananalysis of possible causes and effects of defects and their verification in numerical calculations.
3. The numerical calculations indicated that the weakest structural element of the connector that was most likely to fail during operation was the nut. Therefore, a higher grade material needs to be selected when developing the final design of the new connector.
4. The tests of tensile strength of the prototype connector confirmed the accuracy of results provided by numerical calculations. Similarly as in the case of FEM, the nut proved to be the weakest element and its failure determined the tensile strength of the connector. Prior to launching the connector, it is recommended to manufacture elements with an adequate strength grade or to change the pitch of the stop ridge to a larger one, e.g. 0.5 mm.
5. The tests together with a detailed analysis of results made it possible to verify the accuracy of the theoretical design of the new connector andto develop of technical documentation in the form of working drawings and assembly drawings together with assembly instructions.
6. A small sized connector with a simple design may find extensive applications in connecting panel elements and may be successfully introduced in mass production as a competitive product, comparing to the ones commercially available at present.

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Streszczenie: *Projekt złącza zatrzaskowego do łączenia elementów płytowych*. Celem niniejszej pracy było zaprojektowanie, wykonanie i sprawdzenie wytrzymałości na rozciąganie prototypu złącza zatrzaskowego przeznaczonego do łączenia elementów płytowych.Na wstępie dokonano wnikliwej analizy rozwiązań konstrukcji podobnych złączy znajdujących się na rynku. Dokonano także przeglądu wymagań dotyczących nowoprojektowanej konstrukcji złącza. W ramach poszukiwań najlepszej koncepcji rozwiązania konstrukcji złącza przygotowano trzy propozycje, z których – po przeprowadzeniu wnikliwej analizy konstrukcji – wybrano jedną koncepcję. W kolejnym etapie dokonano udoskonalenia przyjętego rozwiązania tak, aby złącze to spełniało postawione wcześniej wymagania projektowe. Podczas dalszych badańprzeprowadzono analizę rodzajów i skutków możliwych błędów (analiza FMEA), co miało posłużyć ograniczeniu lub wyeliminowaniu możliwych wad. W dalszej części pracy przeprowadzono obliczenia numeryczne przy wykorzystaniu programu AutodeskSimulationMultiphysics. Po wykonaniu prototypu złącza przeprowadzono badania wytrzymałości złącza na rozciąganie przy wykorzystaniu maszyny wytrzymałościowej. Badania eksperymentalne pozwoliły na zweryfikowanie poprawności opracowanej konstrukcji pod kątem geometrii oraz właściwości fizyko-mechanicznych materiału poszczególnych elementów i zaproponowanie ewentualnych zmian w konstrukcji finalnego złącza.

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