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NEW GENERATION OF CABLE SCREW CONNECTORS FOR ELECTRICAL POWER ENGINEERING SYSTEMS

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The article presents a material analysis for a new generation of cable screw connectors with shear bolts designed for not only 1st and 2nd class of cables but also 5th class of aluminium and copper conductors that have not been previously supported. The set of properties of aluminium series 6xxx designated for screw connectors production has been determined. Finite Element Method (FEM) simulation of the controlled shear of the bolt at the body of the screw connector has been carried out. The repeatability of the bolt shear in the actual conditions was also conducted in order to verify the prototypes of the new generation of cable screw connectors.

Keywords: AlMgSi alloy, power cable, screw connectors of cables, stress – strain curve, FEM

INTRODUCTION

Cable connectors used for electrical power engineering systems must ensure a reliable and effective both electrically and mechanically connection. Among the available at the market connectors [1-2] mainly screw connectors with a shear bolts are commonly used, however, they come with some disadvantages and operational problems. These problems are caused by the design and used materials for both the bolt and the connector body. All these combined resulted in search for a new generation of cable connectors for power lines. The idea for the new solution [3-5] (Figure 1) is shearing of the bolt evenly at the connector body after the bolt (with tightening torque M_d) tightened the cable with appropriate F_1 force regardless of the cable type. The concept is possible due to the use of a tubular bolt (1 at Figure 1) with a decreasing wall thickness along the cone and self-generating axial tensile forces F_2 between the body of the connector and head of the bolt. Axial tensile forces F_2 are generated with special discs (2 at Figure 1) placed at the axial hole of the bolt (1 at Figure 1). Presented at Figure 1 connection system is being developed for a whole range of power cables both copper and aluminium of class 1, 2 and 5 with the entire cross-sections range of 10 – 1 000 mm^2.

The bolt with specific geometry and properly chosen materials for pressure system (1-3 at Figure 1) should ensure a controllable shearing of the bolt evenly at the level of the body preventing at the same time formation of sharp edges. These edges are very often the reason for cutting of thermal or cold insulation which are placed at the body of the connectors or may even cause the electrode effect causing partial discharge at the hole of the body. The discs (2 at Figure 1) are responsible for lowering the frictional moment of the tip of the screw (3 at Figure 1) and reversing the direction of the pressure force on the head of the bolt along with the protection from the partial discharge. The tip of the screw (3 at Figure 1) is responsible for direct contact and pressure put on the bolt to the cable placed inside the body of the connector and what is more ensuring the optimal distribution of the wires in the connector.

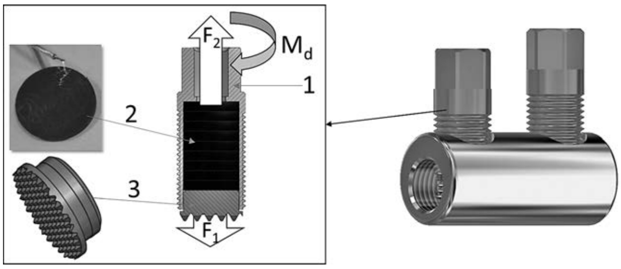

Figure 1 Screw type connection system and load distribution in clamping unit (screw) during screwing. 1 - screw body; 2 – load and current carrying discs; 3 - screw tip

MATERIALS SELECTION AND ANALYSIS

The new generation of cable screw connectors for electrical power engineering systems which is the focus of this paper consists of the body and the pressure system which is built of the tip of the screw and shearing bolt filled with carrying-conducting discs. Each of the elements has a slightly different function therefore different material requirements for each of them needed. The preferred material requires high set of electrical and mechanical properties, and corrosion resistant with

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density as low as possible. Additionally, it is important that the material is easily processed so it does not constitute technological problems during the manufacturing process of the connector. The authors in [6] pointed out that the material selected for the connector and the shear bolt must be precisely designed also in terms of construction and geometry.

Aluminium and its alloys are easily processed due to their high plasticity, they have high electrical and thermal conductivity, high corrosive and abrasive resistance. The undoubted advantage of the aluminium alloys is a favourable Rm to density ratio. Taking that into consideration along with the low price per kg of aluminium it seems only right to choose material for connectors among various types of aluminium and its alloys.

According to EN 573-3:2014 standard [7] there are numerous aluminium alloys used for metal working. Among the known materials over 40 have been analysed basing on data listed in [8-9]. Since the main objective of the analysis is to select materials with an optimal set of mechanical and electrical properties a map of such has been constructed among wrought alloys. Figure 2 presents a portion of the map with high mechanical properties (R_m above 150 MPa) and fairly low electrical resistivity (below 34 nΩm).

The construction of the map presented in Figure 2 made it possible to select the following alloys: EN AW-1050A; EN AW- 1200; EN AW-5005A; EN AW-6005; EN AW-6012; EN AW-6060; EN AW-6063; EN AW-6082; EN AW-6101B; as potentially with the best set of properties for intended applications. It is worth noting that most of the selected materials is 6xxx series Al alloys with alloy additives of Mg and Si. These alloy additives and their content expressed with Mg:Si ratio is the substantial influence on the properties of AlMgSi alloys [10]. An intermetallic Mg_2Si hard and brittle phase is being formed and the alloy additives form a saturated solution of Al with decreasing solubility along with the temperature decrease. Therefore, these alloys may be heat treated by supersaturation and aging, and thus their electrical and mechanical properties may be shaped accordingly [11]. The obtained effect depends on both the content of alloy additives and parameters of heat treatment.

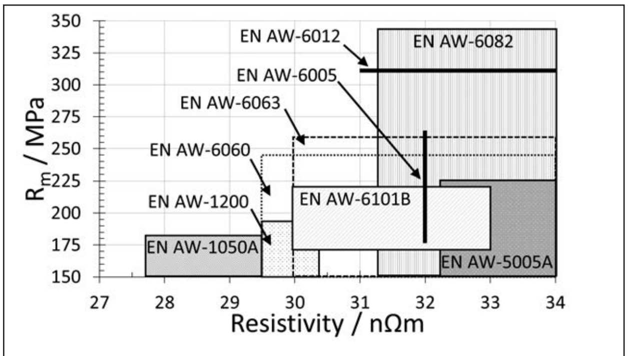

Figure 2 Mechanical and electrical properties map of the wrought Al alloys

Among the alloys presented at Figure 2 EN AW-6082 shows the highest values of mechanical properties along with excellent corrosion resistance, high electrical properties and at the same time it may be easily machined which will be applied for the manufacturing process of new generation of connectors. It should be mentioned that a high content of manganese in EN AW-6082 controls the grain size and further influences its strengthening. According to EN 515:1996 [12] there are five basic tempers of wrought aluminium and alloys, however, EN AW-6082 is usually manufactured for O, T4, T6 and T651 temper, with T6 being of the highest mechanical properties of approx. 300 MPa. The chemical composition of EN AW-6082 in compliance with [7] is presented in Table 1.

Table 1 **Chemical composition of EN AW-6082 (PN-EN 573-3:2014 [7]) / wt. %**

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Other (separately; together)	Al
0,7-1,3	≤ 0,5	≤ 0,1	0,4-1	0,6-1,2	≤ 0,25	≤ 0,2	≤ 0,1	≤ 0,05; ≤ 0,15	rest

FINITE ELEMENT METHOD (FEM)

The main objective of the conducted research was to determine based on the Finite Element Method (FEM) simulations the influence of the wall thickness of M14x1 bolt and the wall taper on the stress, strain and dislocation values after applying 28 Nm tightening torque. The value of the tensile force of the bolt set to 2 kN was assumed based on the additionally carried out experimental research. The variants subjected to FEM analysis were collectively presented in Table 2, whereas the model and the applied boundary conditions were presented at Figure 3. The proposed model was based on the properties of the selected EN AW-6082 alloy in T6 temper obtained in the uniaxial tensile tests which results were presented at Figure 4. The obtained data were further converted according to the plastic-rigid concept of strengthening and applied to numerical simulation software.

The first part of the conducted numerical analyses included the influence of the wall thickness of the bolt with constant taper (0,1 mm) on the entire length of the

Table 2 **Variants subjected to FEM analysis**

#	Wall taper (inside diameter of the bolt at the bottom – inside diameter of the bolt at the base) / mm	Variants analysed in terms of:	
		Various wall thickness of the bolt	Various taper of the walls
1	11,0 – 11,1	X	
2	11,2 – 11,3	X	X
3	11,4 – 11,5	X	
4	11,6 – 11,7	X	
5	11,7 – 11,8	X	
6	11,8 – 11,9	X	
7	11,3 – 11,5		X
8	11,2 – 11,5		X

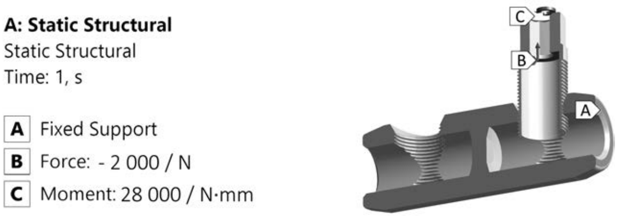

Figure 3 A model subjected to FEM analysis with boundary conditions

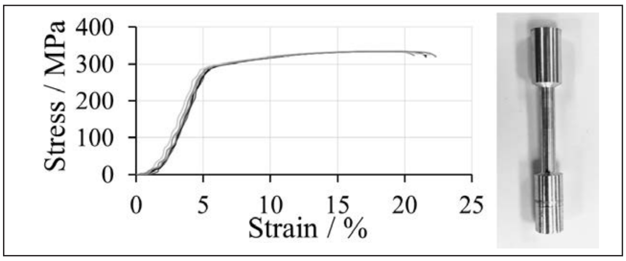

Figure 4 Stress-strain curve of EN AW-6082 alloy in T6 temper

system. Figure 5 presents exemplary results of the stress patterns of variants #2 and #4. The conducted tests show that 11,6x11,7 system (#4) is the most favourable from the point of view of both transferring loads and the location of strains causing shearing.

Further studies included analysis of the taper of the bolt walls at the values of 0,1; 0,2 and 0,3 mm at the length of the bolt (Figure 6). The results suggest that the optimal system geometry in terms of loads transferring and location of the shear is taper of 0,1 mm. For said variant more observable strips of stresses located closer to the last thread of the bolt are visible and the stresses are higher than for any of the other analysed variants.

EXPERIMENTAL RESEARCH ON THE PROTOTYPES OF CABLE CONNECTORS

Subsequent to the prospective materials analysis dedicated for cable connectors and FEM analysis of the

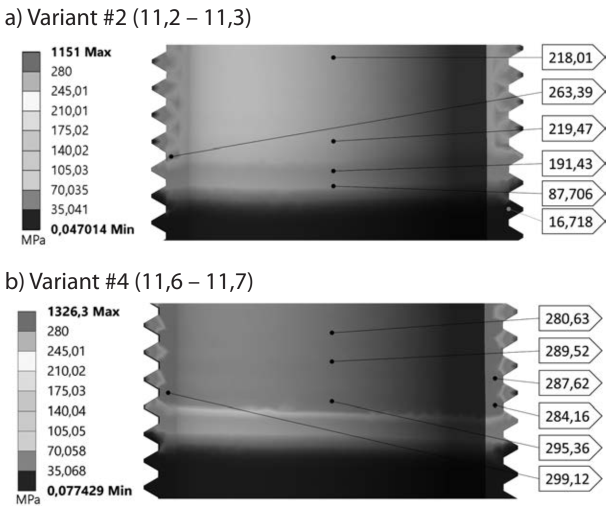

Figure 5 Exemplary results of FEM analysis (stress pattern) for various wall thickness (Variants 2 and 4)

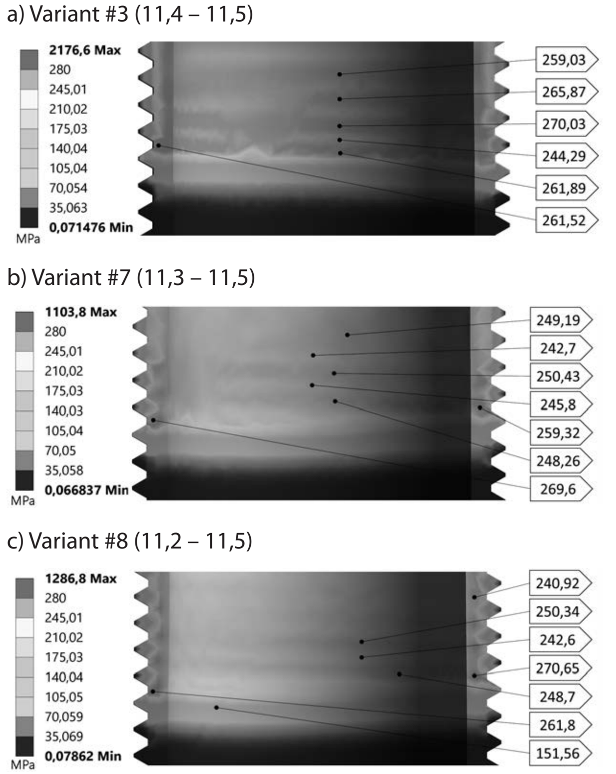

Figure 6 Exemplary results of FEM analysis (stress pattern) for various taper of the walls (Variants 3, 7 and 8)

Figure 7 Connectors with sheared bolts (geometry according to variant #4)

optimal bolt geometry experimental research was carried out verifying the obtained results. Manufactured prototypes of the new generation of cable connectors were subjected to several tests of bolt tightening and shearing in actual conditions. As presented at Figure 7 the repeatability of the bolt shearing at the level of the connector body has been achieved successfully.

CONCLUSIONS

Based on the conducted material analyses, FEM simulations and conducted experimental research the following may be stated:

- material selected for the body and bolt of the connector was EN AW-6082;

- most favourable geometry of the M14x1 bolt was diameter 11,6 mm at the bottom and 11,7 at the base. It had an optimal thickness and taper from the point of view of both transferring loads and the location of strains causing bolt shearing.

The above-mentioned assumptions and guidelines met the requirements for the cable connectors and were confirmed with actual tests in controllable conditions.

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Note: The translator responsible for English language: Andrzej Mamala, AGH University of Science and Technology, Kraków, Poland