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RESEARCH ON THE THREADED CONNECTION SYSTEM FROM AlMgSi ALLOY FOR ELECTRICAL POWER CABLES UNDER VARIOUS CLAMPING LOADS

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This article presents strain gauge tests showing the force loads in the connection system of power cables, with AlMgSi sheer bolts. Among others, the analysis of the influence of the tightening torque of the clamping unit on the distribution of forces and the evaluation of the strain in the entire system was carried out. The knowledge of the force conditions and loads in the threaded connection system allowed to develop, with the use of Finite Element Method (FEM) modelling, the optimal geometry and material of elements for the power cable connection system.

Keywords: AlMgSi alloy, electrical power cables, screw connectors and terminals of cables, screw connectors

INTRODUCTION

Currently, there are several design solutions on the market used to connect different types of cable conductors (differentiated by cross-section, structure and material) [1,2]. As of today, there is no known good solution using connectors and bolt terminations to connect flexible Class 5 cables. However, there are attempts to use this technology by applying a copper sleeve or wrapping the conductor with a brass mesh (Figure 1a). Nevertheless the use of sleeves and mesh, does not guarantee a correctness of a connection, as individual wires can often be destroyed when a bolt is being tightened. When some of the wires in the cable's conductor are cut, it weakens the current-carrying cross-section of the connector. Due to the above there is currently a worldwide growing need to find a solution for connecting Class 5 conductors, but not only made of copper wires, but also made out of aluminium, which compared to copper is much more susceptible to be damaged during connecting process. Figure 1 presents a comparison of two solutions (conventional and newly developed) of screw connectors for class 1, 2 and 5 of conductors, together with the list of their main advantages and disadvantages.

Moreover Authors of paper [3] point out that the reliability of power cable connections mainly depends on: the material of the connector and the connected cable conductor; the construction of the contact element of the connector with the cable conductor; the construction and type of the conductor; the number and arrangement of bolts used in the connector; the tightening torque and the compression force. On the other hand, the authors of works [1, 2] indicate that the tightening torque and the bolt contact force is the factor having the biggest impact on the quality and efficiency of the connection. Therefore, the experimental research carried out in this article

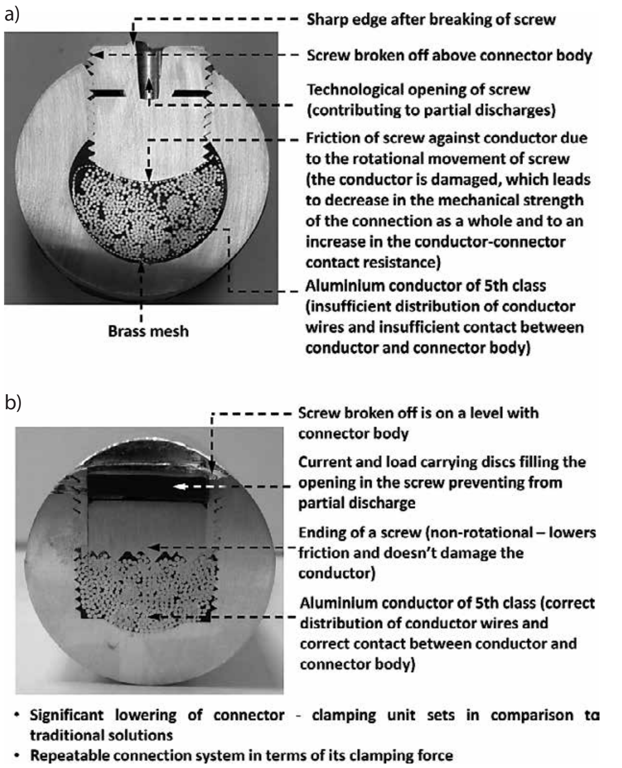

Figure 1 Comparison of two different types of screw connections used to join aluminium conductors of 5 class. Cross section of a) traditional connection system and b) of a new type of connection system.

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focuses on the study of the impact of the tightening torque on the screw clamping force in the newly developed screw connection (Figure 1b).

The new innovative threaded system for connecting power cables with copper and aluminium wires, which was previously in details presented in article [4] and has been reported as an invention [5], consists of two main components, i.e. the connector body and the clamping unit (Figure 2). After applying the tightening torque (M_d) the brass detachable screw tip of the bolt is in direct contact with the cable conductor (due to the F_1 force – Figure 2), and because it is non-rotating, it does not cause damage or deformation to the cable conductors. The load-bearing and conductive disks are aimed to limit the partial discharge and to transfer the longitudinal forces of the conductor to the bolt baffle (Figure 2 – Force of F_2) thus inducing a condition of tensile stress in the bolt section outside the body and leads to the destruction of the bolt at the point of the smallest cross-section. The bolt (made of aluminium alloy of EN AW 6082) itself is shaped like a tube with tapering wall thickness towards the bolt cap. The clamping assembly and a diagram of the forces acting during bolt insertion are shown in Figure 2.

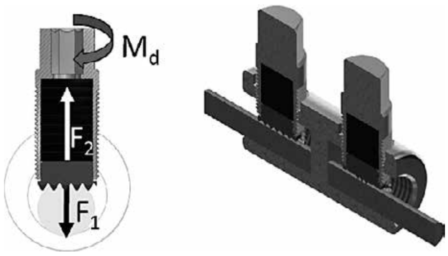

Figure 2 Screw type connection system and load distribution in clamping unit (screw) during screwing.

Additionally it should be mentioned, nowadays more and more popular are becoming aluminium alloys on electrical application. In particular, the 6xxx series alloys, which exhibit high mechanical, electrical and exploitational properties and at the same time have good machinability, which makes it easy to manufacture connectors, even with complicated shapes. The authors of the papers [6, 7] also points out that when aluminium conductors are joined with copper connector, the difference in thermal expansion between these two materials leads to potential problems. As a result, the quality of the connection may deteriorate, which will affect the further operation of such a connector, which again argues in favour of using connectors made out of similar materials as the conductors.

EXPERIMENTAL PART

It is very difficult to determine the actual forces that occur during the tightening of a bolt in cable conductor. Usually, the analytical methods presented in [2, 8], among others, are used for this purpose. However, due to the complex characteristics of the forces occurring in the new connection system showed in Figure 2 and the need to guarantee that the clamping system breaks in a strictly defined plane, a theoretical analysis of the assembly conditions within the connection system and the breakage of the clamping element was carried out by the authors of this paper. This analysis was based on experimental studies on the tightening torque (M_d) influence on the stress distribution in the clamping system (with an M12 x 1 screw) and the evaluation of its strain as a function of the tightening torque. The F_1 force (clamping force of the clamping system on the cable conductor) was recorded using a force sensor, while F_2 (tensile force of the clamping unit walls)was determined from strain gauge measurements showing the amount of deformation (ε) of the outer walls of the bolt body of the clamping unit. Test was carried out with tightening torques starting from 15 Nm and holding the specimen under the load for 30 seconds. The specimen was then unloaded and reloaded with torque of 1 Nm higher than the previously applied one. During the test, the continuous clamping force (F_1) and the tensile force of the bolt wall of (F_2) were measured in all cases.

RESULTS AND DISCUSSION

As part of Test, strain gauge measurements were taken at the outer wall of clamping assembly bolt under a given tightening torque. The value of deformation made it possible to estimate the amount of tensile force (F_2) of the bolt wall. At the same time, the clamping force (F_1) of the clamping assembly against the cable conductor was measured. In fact, the range of the tightening torque was realized for 15 Nm, 16 Nm and 17 Nm. Figure no.3 shows the characteristics of force (F_1 and F_2) and strain versus time for a given tightening torque, obtained from the experimental tests.

Analysis of the acquired data shown on the graphs, indicates that after the specimens were unloaded and tightened with a torque of 15 Nm and 16 Nm, the force and strain values returned to the level from before the process of tightening the bolt, i.e. to the 0 position. This fact proves that force parameters were in the elastic range of the material deformation. A different situation is observed for the case study where tightening torque was 17 Nm. In fact, when the specimen was tightened with a torque of 17 Nm, the strain gauge was damaged, which proves the occurrence of plastic deformation of the clamping assembly beyond the measuring range of the strain gauge. After this experiment, it was decided to run another test in which the specimen was tightened until broke. The last recorded value of F_1 force corresponded to a tightening torque of 21 Nm, while at 22 Nm the M12x1 bolt of the tested compression assembly broke. In fact, from a tightening torque of 16 Nm until the bolt breaks, the level of the F_1 clamping force varies slightly within the range of 10 - 11 kN. This is a result of the so-called “flanging” of the clamping unit walls at

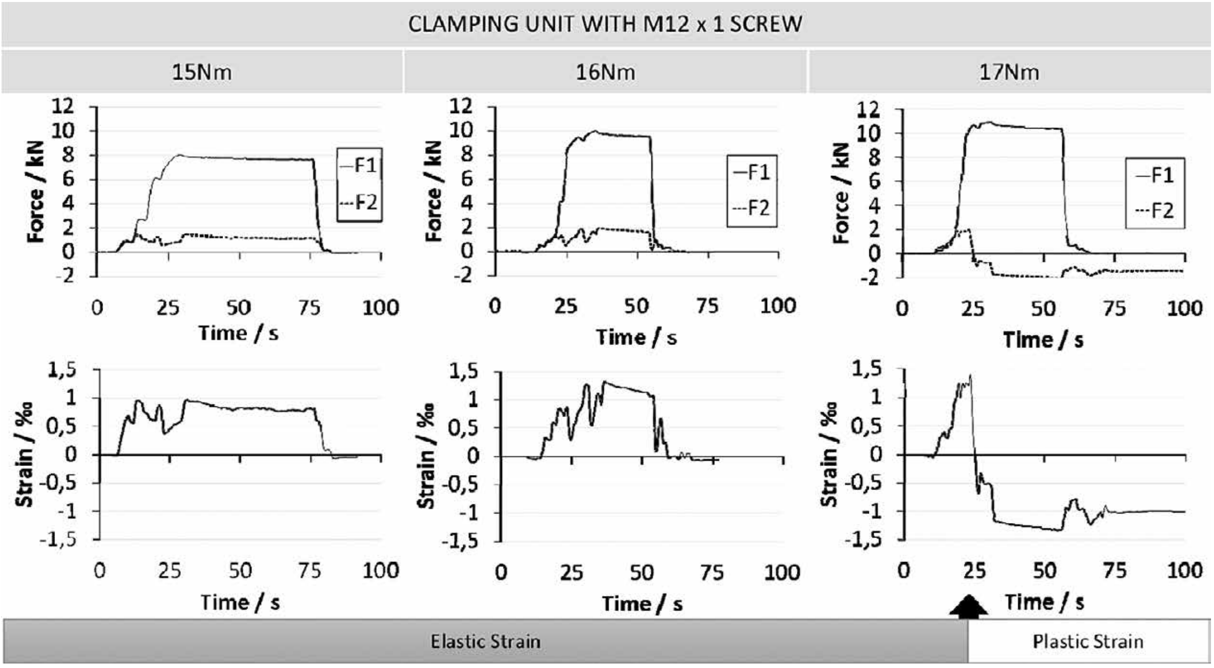

Figure 3 Influence of clamping unit torque moment for M12x1 screw on clamping load (F_1) and tensile force within screw wall (F_2)

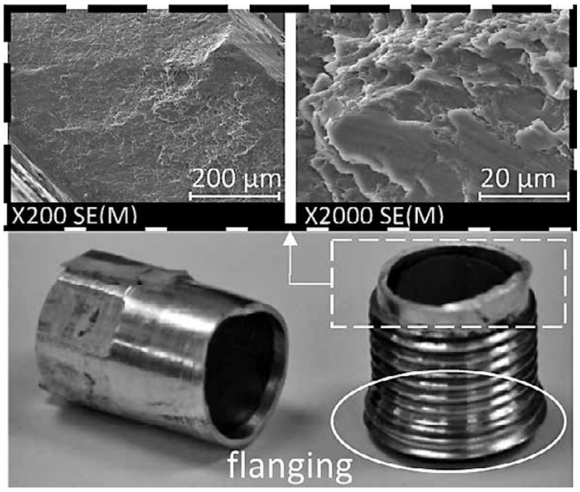

Figure 4 Belling of M12x1 clamping unit screw during its screwing with 21 Nm torque moment and scanning electron microscope (SEM) of fracture

its base (Figure 4), so that no increase in the clamping force of the system is generated, and the force from the tightening torque translates precisely into deformation of the bolt walls. At the same time, an increase in the tightening torque above 17 Nm leads to the initiation of the bolt break.

Summarizing, it can be seen that for every case the value of the clamping force (F_1) is much higher than the tensile forces of the clamping system (F_2). In case of M_d = 15 Nm, it generated about 8 kN for F_1, and this was translated into a level of tensile force on the walls of the clamping assembly F_2 slightly above 1 kN. On the other hand, for M_d = 16 Nm, the F1 force was about 10 kN and F_2 was 1,97 kN. In case of the tightening torque of M_d = 17 Nm, the initial loading stage generated an F_1 force value of 10,9 kN and an F_2 force value of 2,07 kN, followed by plastic strain of the clamping assembly and damage to the strain gauge (out of the measurement range). Subsequent loading with torques up to 21 Nm did not result in significant changes to the generated value of the F_1 clamping force, which oscillated around the value of 11 kN. Increasing the torque above 17 Nm is the reason for the start of bolt rupture, and due to the fact of flanging, the lower part of the clamping system, it does not generate an increase in the clamping force of the system. On the basis of obtained test results, it was also found that during the loading of bolts with the analysed geometry, the value of the clamping force of F_1 in the whole range starting from the tightening torque of 16 kN is about 11 kN, which translates into the value of the force of F_2 stretching the screw wall at the level of about 2 kN.

CONCLUSIONS

Summarizing the results from the strain gauge tests of the clamping force measurements the following conclusions have been made, which at the same time served as guidelines for following numerical FEM simulations (which were presented in following article [6]) on the optimization material and shape of the clamping assembly:

- It was confirmed that elastic deformation of the tensile bolt walls of the analysed clamping system occurs for tightening torques up to 16 Nm. The increase of the torque to 17 Nm and above causes irreversible deformation of the screw walls and its cup in the downstream part of the clamping system (it does not generate an increase in the clamping force of the system) , up to M_d = 22 Nm, at which the clamping assembly breaks (for the system geometry analysed in the research).
- Based on the analysis of the test results obtained, it was concluded that for a tightening torque condi-

tion within 16 – 17 Nm, two values of the forces occurring in the new innovative bolted power cable connection system would be adequate, namely:

– clamping force F_1 of the clamping assembly equal to 10-11 kN
– tensile force of F_2 of the clamping unit wall equal to 2 kN.

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