Experimental study of friction in aluminium bolted joints

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ABSTRACT. This study aims at developing an experimental tool useful to define accurately the friction coefficients in bolted joints and, therefore, at relating precisely the tightening torque to the bolt preloading force in some structural components of front motorbike suspensions. The components under investigation are clamped joints made of aluminium alloy. The preloading force is achieved by applying a specific torque to the fastener, by means of a click-type torque wrench. Appropriate specimens have been designed by the authors in order to study the tribological aspects of the tightening phase. Then, experimental tests have been performed by applying the Design of Experiment (DOE) method in order to obtain a mathematical model for the friction coefficients. Three replicas of a full factorial DOE at two levels for each variable have been carried out. Levels include cast versus forged aluminium alloy, anodized versus spray-painted surface, lubricated versus unlubricated screw, and first tightening (fresh unspoiled surfaces) versus sixth tightening (spoiled surfaces). The study considers M8x1.25 8.8 galvanized screws.

INTRODUCTION

Threaded fasteners are used in many mechanical and structural applications because of the easiness of the assembly and disassembly operations for maintenance and repair purposes. Both the level and the stability of the clamp loads, which are created by the tightening process, will govern the safety and reliability of bolted joints. In most of production applications, the fastener tension (preloading force) is achieved by using a torque wrench applied to the head or to the nut. The tribological aspects of the fastener tightening are critical to define the actual torque-tension relationship [1]. The tightening torque is mostly consumed in overcoming two friction components: the underhead friction due to the sliding of the fastener head on the flange and the thread friction consumed between the male and the female thread. The residual torque component produces the fastener tension by generating the joint clamping force. Inaccuracies in determining the friction components may lead to an overestimation or underestimation of the bolted joint performances.

The aim of this study is to provide an experimental procedure useful for determining accurately the friction coefficients in bolted joints and for relating precisely the bolt torque to the bolt preloading force. The components under investigation (Figure 1) are some clamped joints made of aluminium alloy [2] and used in front motorbike suspensions to connect the steering plate (fork) to the legs and the legs to the wheel pin. The aluminium alloy is realised by a casting or a forging process afterwards anodized or spray-painted in surface.

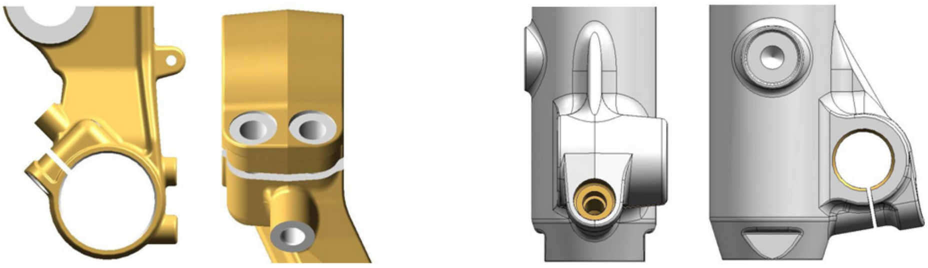

(a) (b)

Figure 1: Example of bolted joints in front motorbike suspensions: a) steering plate-leg b) leg-wheel pin.

RESULTS AND DISCUSSION

Some specific specimens reported in Fig. 2 have been appropriately designed and realized with the same process of the actual components.

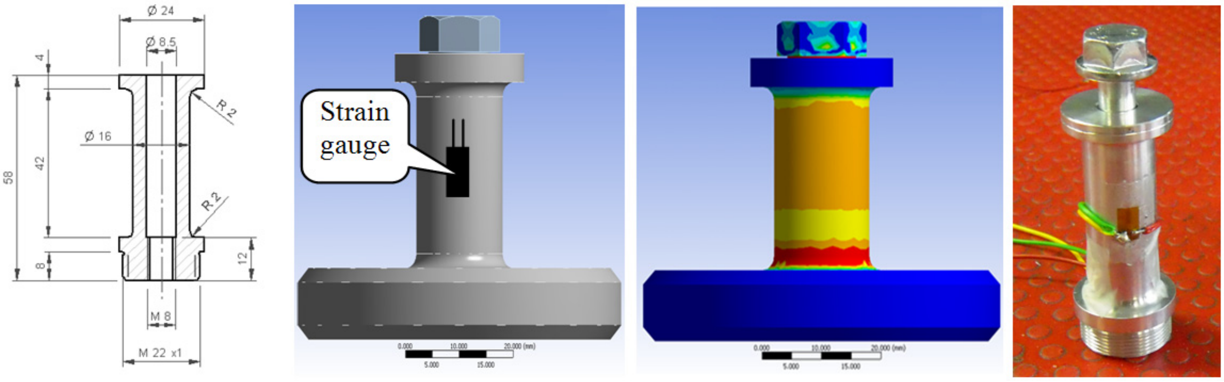


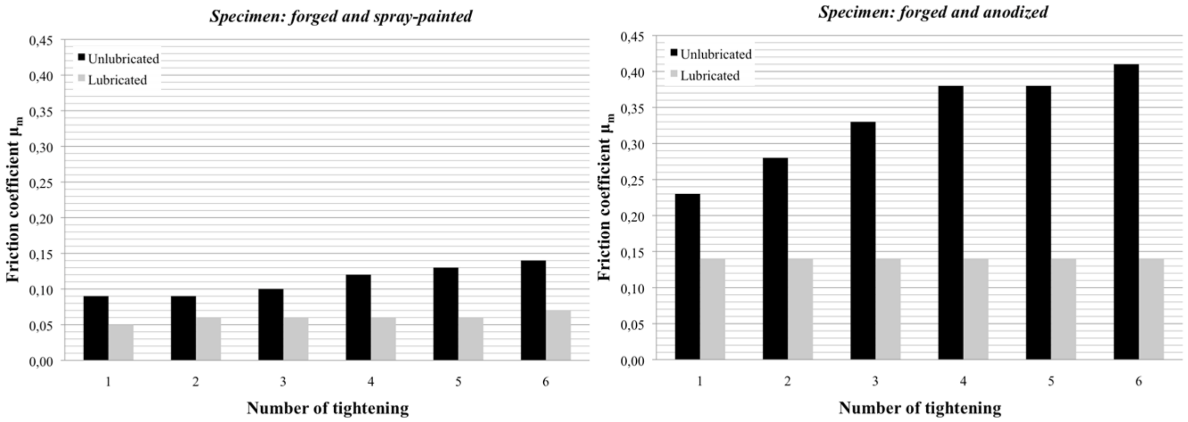
Figure 2: The specimen useful to the friction coefficient definition.

The bolt torque is given by a torque wrench whereas the preloading force has been evaluated by means of a strain gauge located on the external surface of the specimen, which is able to read the axial compression, exactly equal to the preloading force, since the system is a connection of mechanical springs in series. A Finite Element Analysis (FEA) has demonstrated that the whole cross section (circular and hollow) in the central part of the specimen has the same strain and, therefore, the same stress. Thus, it is possible to calculate the compression force acting on the specimen, which is the same tensile force (preloading) acting on the screw. The thread and underhead friction coefficients have been evaluated separately [3] by applying an axial bearing located between the bolt head and the specimen and by using equation (1). Finally the torque coefficient K (Eq. 1) has been calculated. Experimental tests have been performed by applying the Design of Experiment (DOE) method [4-6] in order to obtain a mathematical model for friction coefficients. Three replicas of a full factorial DOE at two levels for each variable have been carried out. The levels include cast versus forged aluminium alloy, anodized versus spray-painted surface, lubricated versus unlubricated screw, and first tightening (fresh unspoiled surfaces) versus sixth tightening (spoiled surfaces) [7,8]. The study considers M8x1.25 8.8 galvanized screws.

$$\begin{cases} M_{torque} = F_{preloading} \cdot \left(0.16 \cdot pitch + 0.58 \cdot \mu_{thread} \cdot d_{mean\_thread} + 0.5 \cdot \mu_{head} \cdot d_{mean\_head}\right) \\ M_{torque} = K \cdot F_{preloading} \cdot d_{nominal} \end{cases} \qquad (1)$$

Surface finishing (specimen spray-painted or anodized), lubrication (specimen lubricated or unlubricated), the interaction between surface finishing and lubrication, and finally the tightening number are the most significant parameters. In the bars diagrams of Fig. 3 some results are compared depending on the aforementioned parameters in case of forged specimens.

It is possible to highlight that the spray-painted specimens present the lower friction coefficients (the higher preloading forces F_V). For example, in presence of unspoiled surfaces, the overall friction coefficient μ_m decreases from the value of 0.26 in case of forged, anodized and unlubricated specimens to the value of 0.11 in case of forged, spray-painted and unlubricated ones, so that the preloading force doubles with the same tightening torque T=15Nm. Lubrication always increases the preloading force: in presence of forged and unspoiled surfaces, the overall friction coefficient μ_m decreases from the value of 0.11 to 0.08 in case of spray-painted specimens, and from the value of 0.26 to 0.17 in case of anodized ones. Finally, considering the effect of the number of tightening and loosening (up to six maintenance operations in a standard motorbike lifecycle) the preloading force is affected by the tightening replicas mainly in case of unlubricated and anodized surfaces so that the preloading forces progressively decrease for the same tightening torque. As a matter of fact, the surfaces are subjected to wear and spoiling by increasing the number of tightening, while lubrication creates a sort of protective film. In presence of spoiled surfaces, the overall friction coefficient μ_m increases from the value of 0.26 to 0.39 in case of forged, anodized and unlubricated surfaces, whereas from the value of 0.16 to 0.17 in case of forged, anodized and lubricated surfaces.



(a) (b)

Figure 3: Bars diagrams of the friction coefficient μ_m values for forged specimens ((a): spray-painted (b): anodized) in case of tightening torque T=15Nm (different series for lubricated and unlubricated specimens).

REFERENCES

[1] S.A. Nassar, H. El-Khiami, G.C. Barber, Q. Zou, T.S. Sun, Journal of Tribology, 127 (2005) 263.
[2] D. Croccolo, R. Cuppini, N. Vincenzi, Finite Elements in Analysis and Design, 45 (2009) 406.
[3] S.A. Nassar, P.H. Matin, Journal of Pressure Vessel Technology, 127 (2005) 387.
[4] D. Croccolo, R. Cuppini, N. Vincenzi, In: ICEM13, – paper n.176.
[5] D. Croccolo, R. Cuppini, N. Vincenzi, Strain, 44 (2008) 170.
[6] S.A. Nassar, S. Ganeshmurthy, R.M. Ranganathan, G.C. Barber, ASME Journal of Pressure Vessel Technology, 129 (2007) 426.
[7] J.H. Bickford, An Introduction to the Design and Analysis of Bolted Joints, 3rd ed., Marcel Dekker, New York (1997)
[8] N. Motosh, ASME J. Eng. Ind., 98 (1976) 849.