Strength of Thread Turns Under Static Load on a Fastening Threaded Connection

"Fine thread turns play an important role!"

Introduction

Thread turns of metric profile or projections on the surface forming a spiral are an integral part of the fastening threaded connection (FTC). Thread turns must ensure the reliability and strength of the FTC between fasteners (stud, bolts, nuts), as well as the integrity of the fastened components of the working structure. Due to the thread turns in the FTC, the force is transmitted with its fixation, thereby ensuring the tightness of the joint of the working structure. High static loads on the FTC should not lead to problems in the operation of the working structure.

> ***In this regard, when designing FTC for large-sized and loaded structures and systems, it is important to optimally use the strength of thread turns made of high-strength steels with acceptable viscoplasticity. The static strength of the metal of fasteners depending on the geometry of the thread turns is an important criterion for the functionality of the FTC due to the absence of destruction of the thread turns by the shear mechanism.***

FTC, as a rule, is tested or assessed under conditions of high tensile loads when tightening using torque or preliminary hydraulic jacking of the stud. The following FTC testing methods are most widely used:

- √ *Direct axial force loading in testing machines;*
- √ *Loading during tightening with a nut by torque. Where the performance of the FTC is limited by the destructive load, i.e., the minimum external force or stress causing irreversible deformation and destruction.*

The first method is the most widely used, characterized by the simplicity and accuracy of determining the strength of the FTC. The second method is used for workpieces during tightening, for example, of prefabricated structures and units during bridge construction, in the construction industry for frame-beam structures, etc. Experience in the operation and testing of FTC has shown that the following types of destruction are most common:

- √ *Fracture of the stud (bolt) shank along the thread by a shear mechanism, caused by the influence of the fastener metal's tendency to brittleness or by the destruction of the stud (bolt) body (smooth part) with good viscoplasticity of the fastener metal;*
- √ *Destruction of the thread turns by shearing or crushing.*
- √ *Failure of the thread turns by cutting or crushing them.*

If the length of the screwing of the turns of the FTC is insufficient, as well as if the mechanical properties of strength and ductility of the metals of the stud and nut differ, the failure of the FTC occurs by cutting the turns. The turns are cut off at a larger diameter than the internal diameter, taking into account the thickness of the nut walls as well as the initial overlap of the turns and weakening of the FTC.

With minimal overlap of turns (H 1 and H min are the theoretical and minimum working height of the profile, respectively), determined by the equality H 1 ~ H min, (1), and the mechanical properties of the metal of the stud and nuts, plastic bending of the turns and crushing of the thread may occur. The strength of the FTC in this case is significantly less than when the turns are cut.

> ***The aim of this study was to experimentally evaluate the influence of the thread geometry of metric profile turns on the strength of the FTC with different make-up lengths. To identify the strength potential of thread turns at the level of or higher than the strength of the stud (bolt) body. Data on such studies are important not only for assessing the performance of the FTC under high loads, but also for choosing the optimal thread geometry based on a small pitch. The use of a large (recommended pitch in standards, small pitches are optional) thread pitch is not effective enough to increase the strength of the stud (bolt) body.***

Discussion and Analysis of the Results

Thread deformation and destruction is a serious and common cause of FTC failure, associated with preload to achieve connector tightness and integrity of the working structure, such as a high-pressure vessel, as well as operational loads from temperature and pressure increase. It should be noted that according to the operation data of South Korean nuclear power plants from 1980 to 2005, about 350 cases of FTC failures were identified and analyzed. The main share of FTC degradation was mechanical damage at 90 cases and the remaining 240 cases without determining the cause. Factors such as corrosion, wear, vibration and fatigue in total accounted for only 67 cases. [1]

The main design parameters determining the strength of the threads are the diameter d, the thread pitch P, the nut height H (the screw-on length l or the H/d ratio). The strength of the thread turns was investigated for the "stud-nut" workpiece, where the fasteners were manufactured by cutting the thread with a cutter from medium-carbon low-alloy steel grade A 193 B7 (ASTM A193/ASME SA193 standard) and alloy steel grade SA-540, Grade B23, B24 (ASTM A 540/A 540M standard) of the pearlitic class. In this case, the former steel was selected as a "brittle" fastening steel with the following mechanical properties at T = 20ºC: Rp 0.2 = 860-870 and R m = 975-985 N/mm^2; A 5 = 15-17 and Z = 62-65%; KCV = 10-40 J/cm^2; the percentage of fiber in the fracture of the impact sample KCV 5-15%.

For steel SA-540: Rp 0.2 = 910-920 and R m = 1015-1025 N/mm^2; A 5 = 15-20 and Z = 62-65%; KCV = 90-100J/cm^2; the percentage of fiber in the fracture of the impact sample KCV 100%. Moreover, 100% of the fiber was also at a temperature of minus 40ºC. According to the criterion of 50% fiber in the fracture, provided that KCV is not less than 59 J/cm^2, the critical brittleness temperature was minus 50 and plus 50ºC for steels SA-540 and A 193 B7, respectively. The difference in the temperature reserve for the critical brittleness temperature was 100ºC, which indicates a significant difference in the resistance of fastening steels to brittle fracture. To study the strength of the thread turns for the FTC, the nominal thread diameter M12 was selected. The thread pitch was: 1.0; 1.25; 1.5 and 1.75 mm. Tests of the FTC M12 under axial tension were carried out on an electromechanical setup with a force of 120 kN (12 tons) at a temperature of T = 20ºC and a gripper travel speed of 3-4 mm/min (ISO 6892-1 and ASTM E8 standards). To assess the influence of the thread turn geometry, the following make-up lengths H/d were used: 0.25; 0.5; 0.75; 1.0 and 1.5, where H is the nut height, and d is the nominal thread diameter.

The test results are shown in **Fig. 1 and 2**. At make-up lengths H/d < 0.75, the destruction of the stud thread turns by shearing was observed. In this case, the value of destructive stress increases almost proportionally to the increase in the make-up length to H/d = 0.75-0.80. On inclined sections of short make-up lengths (H/d<0.75), where the destruction of the FTC is associated with shearing of the turns, a decrease in the pitch leads to a slight decrease in the destruction stress of the FTC. In this case, a large pitch of 1.75 mm makes it possible to obtain a very small advantage in the values of the critical stress, as well as in the value of the destructive load. At a make-up length H/d > 0.75, the destruction of the FTC in almost all cases occurred along the body (smooth part) of the studs. On horizontal sections of long make-up lengths, the higher destructive loads, the smaller the thread pitch.

Fig.1 and 2 *also show that the destructive stresses on inclined sections of the strength of thread turns with small screwing lengths had practically no dependence on the geometry of the thread. Whereas on the horizontal section the maximum destructive load was determined by the influence of the internal diameter of the thread and, accordingly, the geometry of small thread pitches.*

Fig. 1. Fracture stresses of the M12 fastening threaded connection depending on the make-up length. The material of the studs and nuts is A 193 B7 steel. P is the thread pitch.

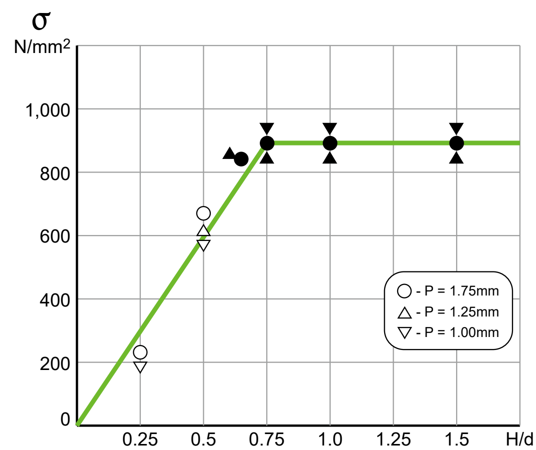
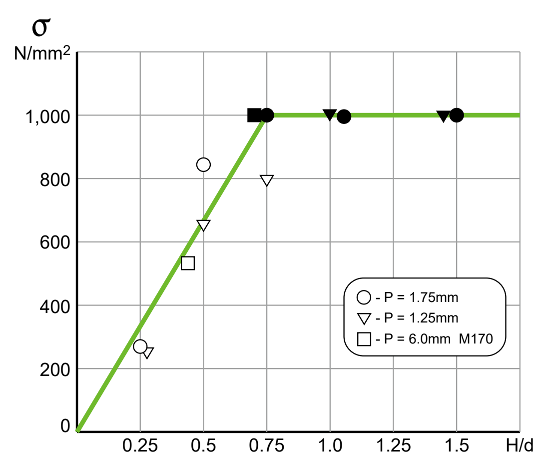


Fig. 2. Fracture stresses of M12 and M174x6 fastening threaded connections depending on the make-up length. The material of the studs and nuts is SA-540 steel.



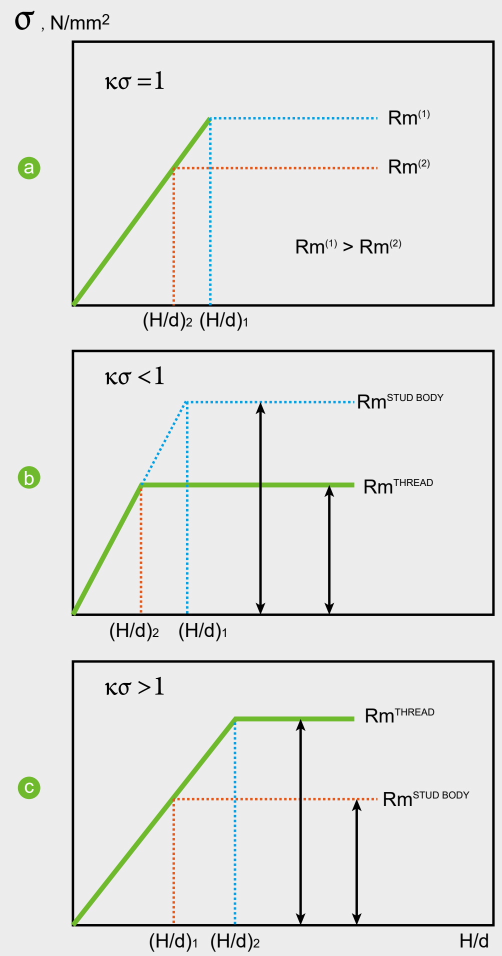
It should be noted that in the present additional studies of static strength, the scale factor did not show any effect on the shear of the thread turns and the destruction of the body of the FTC M174x6 (thread pitch factor) stud made of high-strength and viscoplastic steel SA-540 for screwing lengths H/d = 0.41 and 0.69, respectively. The FTC M174x6 tested on the hydraulic machine (force up to 3000 tons) had the finest thread with a ratio of d/P = 29, while the conventionally fine or actually very coarse thread M12x1.0 had d/P = 12, which is more than 2.4 times larger than the M174x6 thread. It can be noted that the screwing for loaded FTC is usually recommended within the range of (1.0-1.2) d, which is 1.25-1.5 times greater than in the case of H/d = 0.8, when the strength of the FTC is limited by the body of the stud. [2]

A study of the strength of thread turns taking into account the loading of the FTC in structures under pressure, as well as data from **Reference 3**, showed that the ultimate load corresponding to the failure diagram in **Fig. 1 and 2** can also be determined by the strength and sensitivity of fasteners to stress concentration in the thread. The sensitivity coefficient to stress concentration in the thread of a turn is conveniently characterized by the following relationship : K б = R m (thread) / R m (stud body) , where R m (thread) and R m (stud body) are the ultimate strength taking into account stress concentration in the thread and the smooth part of the stud, respectively. At K б > 1, the FTC failure occurs along the stud body, which corresponds to the horizontal section of the strength of the thread turns. At K б < 1, the FTC failure occurs by cutting the thread turns. **Fig. 3** shows the ultimate fracture diagram of the FTC, consisting of 3 schemes, taking into account the strength and sensitivity of the fastening steel to the concentration of stresses in the thread. These diagrams allow us to systematize the following variants of thread strength:

- √ *For fasteners that are not sensitive to the influence of threads, an increase in the strength level of the FTC metal ensures maximum destructive load in accordance with an increase in the screwing length (Fig.3a);*
- √ *For fasteners that are sensitive to threads, the destruction of the FTC in the first most loaded thread turns is possible even at short screwing lengths until the FTC is destroyed by cutting off the turns (Fig. 3b);*
- √ *For fasteners that are strengthened by stress concentration, it is advisable to increase the screwing length in order to ensure the reability of the FTC.*

Studies have shown that the FTC stud-nut M174x6 with the finest thread (d/P = 29) made of viscoplastic steel SA-540 with a yield strength of 1000-1100 N/mm^2 with a screw-on length of H/d 0.7-0.8 provides strength along the stud body due to the increased resistance of the thread turns to shear failure. It can also be noted that the existing division of thread pitches into normal, main large and small pitches (4-5 small pitches per 1 large pitch) in accordance with the standards (ISO 724, DIN 13, ANSI/ASME B1.13M) is conditional. Since the small pitch can also be considered normal and main, providing not only the strength of the thread turns, but also the increased load-bearing capacity of the FTC with a screw-on length of H/d = 0.75 and more. A small pitch with a known increase in the net cross-sectional area of the studs (bolts) significantly reduces the level of their tension stresses, which can constitute a significant proportion of the yield strength of the metal. At the same time, there is a critically small pitch in the ranked series of small pitches for one nominal thread diameter, which reduces the strength of the FTC due to destruction of the thread turns by the shear mechanism while maintaining the integrity of the stud body.

Fig. 3. Limit diagram of failure of thread turns of a stud-nut fastening connection depending on the make-up length: a) the stud material is not sensitive to stress concentration in the thread; b) the stud material is sensitive to stress concentration in the thread; c) stud material hardening under the influence of stress concentration in the thread.



Conclusion

The strength of the thread turns of the stud-nut connection M12 and M174x6 in the range of the nominal diameter to pitch ratio d/P 6,85 - 29 depends on the make-up length H/d (nut height/nominal diameter) in the range of 0.25-1.5, where the range in the thread geometry by the pitch parameter is a factor of this influence. With a make-up length H/d less than 0.75, a large pitch of 1.75 mm provides a slight advantage in the strength of the M12 thread turns during shear compared to small pitches of 1.0 and 1.25 mm. At the same time, a make-up length of thread H/d less than 0.75 reduces the strength of the thread turns almost independently of the value of the pitch parameter. The highest strength of the M12 thread turns was provided by a small pitch of 1.0 mm, provided that the make-up length H/d = 0.75 and more. It has been established that the static strength of the M174x6 thread turns with the highest degree of thread refinement (d/P = 29) exceeding d/P for M12x1.0 by 2.4 times, corresponds to the strength of the M12 thread turns on the inclined and horizontal sections of the dependence of the destructive stresses on the make-up length H/d in **Fig. 1 and 2**. It has been established that a fine pitch, which is not a normal or main pitch, ensures the strength of the thread turns of the connection with a make-up length H/d of at least 0.75 more than a coarse pitch and the stud body, which allows us to consider such a fine pitch also a normal or main pitch, ensuring the strength of the threaded connection with a make-up length H/d of 0.75 and more at the level of or above the strength of the stud body. ■

References

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