Strength of thermal drilled threaded holes

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Abstract: The paper presents experiments on strength of bolted connections with threaded holes. The results compare different types of technology used for thread manufacturing. Especially thermal drilling technology. The method is tested on various types of steels, including both mild grade and high strength steel types. The results are analysed compared to standardized values. As a conclusion, this paper presents a technique to make estimations about such connections strength.

Keywords: Flowdrill; thermal drilling; Thread Stripping; DOCOL; Bolted Joint

1 Introduction

In case of bolted joints, there are basically three types of static failures according to ISO standards [1]. It is desirable though, to design a joint so, that a failure occurs in the bolt shank and thus preventing a thread stripping. To achieve this, several procedures have been developed by Alexander [2] and verified and optimised by Hagiwara [3]. These works are however focused mainly on bolt-nut connections to optimise each configuration according to its property class and geometry. When nuts are replaced by threaded holes for convenience, the thread stripping is no longer avoided automatically and assessments of the thread stripping have to be made.

Acc. to Alexander's theory [2], if the shear area of a thread is insufficient, the stripping occurs before a tensile failure in the bolt shank. There are many factors contributing to the shear area, however, a so called effective length of engagement of a thread is one of essential variables. Achieving a proper length of engagement with holes drilled in thin plates was rather difficult until introduction of the thermal friction drilling technique [5].

The friction drilling technique is a very useful and quick way to create a threaded hole in thin plates without using any additional material or removing any. The basic principle is to use the material which would be removed otherwise to extend the depth of the hole by creating an extruded sleeve. This is achieved via plastic deformation of the metal that is being machined. The thread itself could be then cut or formed again using plastic deformation Fig. 1.

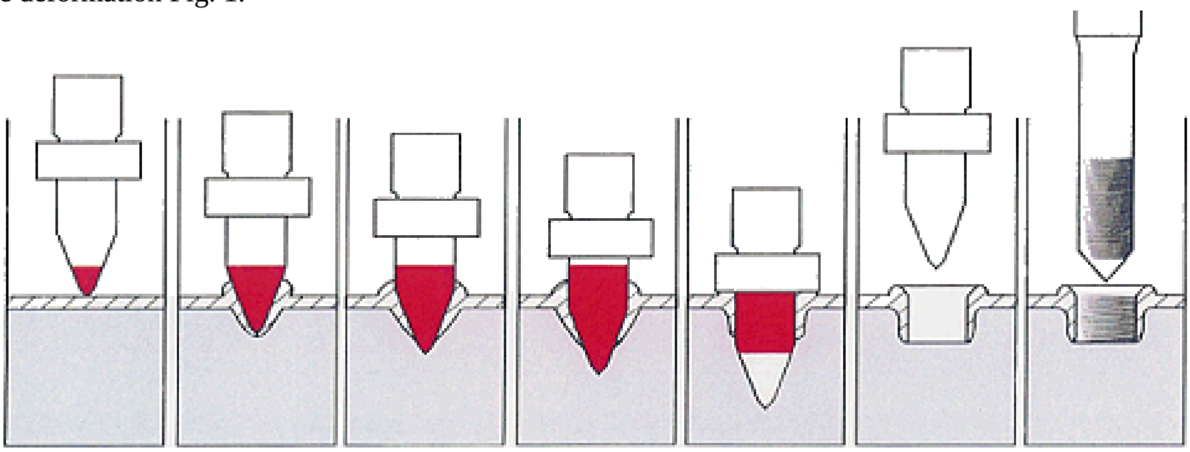


Fig. 1: Thermal drilling process illustration [5].

However, many calculations for the thread stripping in such as in [4,6] do not take into account main characteristics of this technology, such as sleeve geometry, thermal softening, etc. Thus, an experimental verification is very useful to determine if standard procedures could be extended to this case as well. Such study is described below on various sets of geometries and materials.

2 Method of Evaluation

Following many procedures and standards [1,6], joint is required to withstand certain amount of axial tensile force according to its size and property class. A similar approach is used to evaluate joints presented in this study on both mild and high strength steel types. There are three material types considered in this study. Two mild steel grades S235 and S355 according to EN 10025 [7] and a DOCOL high strength steel acc. to its datasheet [8]. In addition, each material specimen was subjected to a uniaxial test for obtaining reference values of tensile strength for verifying calculations.

It is obvious, that the reliability of this method depends on the thickness of the base material very much. It affects the sleeve length and has a direct relationship to the effective length of engagement. However, not all types are available for all sets of materials, 2mm and 3mm thick specimen (before drilling) were considered.

To study this problem more thoroughly another set of parameters was added to the evaluation. Three metric thread sizes were considered: M5x0.8, M6x1, M8x1.25. All these parameters listed above were included into the specimen fabrication.

3 Experimental setup

As many standards refer to axial force values as a measure of joint strength [1,2,6], the same approach was used and presented in this paper, e.g. an axial tensile force associated with any mode of failure. The joints were evaluated in a tensile testing device in order to obtain a force-displacement relationship.

It is clear, that the design of tested specimens could affect the results heavily. The design was focused on minimising negative influences such as eccentricity or stiffness effects. A radially symmetrical specimen constraint at its edges was proposed for such solution, see Fig 2. below. An interface between a specimen and the testing device was specially designed for this experiment to satisfy clamped constraints. High property class 12.9. bolts were used for all configurations. The load rate was constant for all measurements 5mm/min.

a) specimen b) test rig

Fig. 2: The tensile testing device with the interface for a clamped specimen.

4 Results

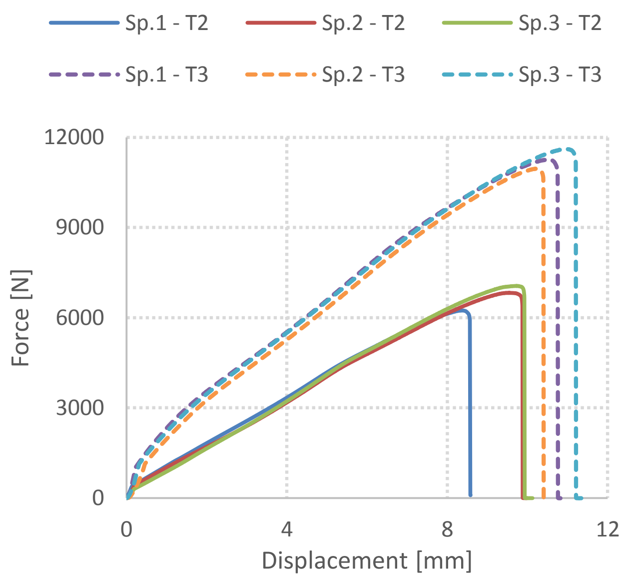
A relationship with its failure load is obtained from each measurement. Each measurement was done thrice. Since this is a destructive testing, there were three samples total for each measurement.

Since high strength bolts were used on purpose to avoid tension failures, the thread stripping is a major type of failure both on internal or external threads. None of tested configurations resulted in a breakage of the bolt shank. In addition to standard failures described in standards[1], threaded holes fabricated using the thermal drilling technology showed a new type of failure, where the sleeve formed by the technology separated from the base material resulting in a fatal loss of its functionality.

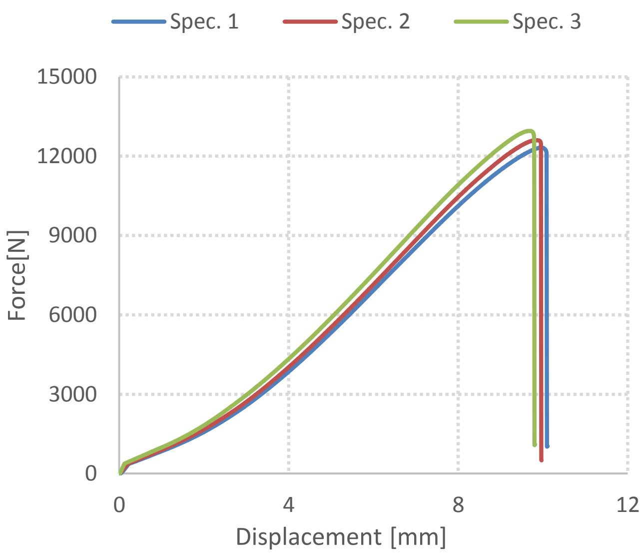
Fig. 3: Failure mode of a broken sleeve. Specimen shown from below.

All measurements were done thrice, where results are evaluated as an arithmetical average. Although force-displacement relationships show a distinct stiffness behaviour for mild and high strength steel types, it can be observed however, that there are no major discrepancies among each sample result sets.

Although all specimen were subjected during testing to relatively large plastic deformations around the thread (see Fig. 3), Graphs in Fig. 4 do not show any significant softening during the whole process of testing. All configurations with mild steel grades showed a relationship similar to Fig. 4a. The situation was similar in case of high strength steels with thickness 2 mm, where all configurations showed the same initial hardening as in Fig. 4b. The graphs below show results for samples of size M5 only, since the relationships are similar as explained above.



a) S235JRG1 mild steel – thickness 2 and 3 mm



b) SSAB DOCOL 1200M high strength steel

Fig. 4: An example of force-displacement relationship for size M5

Overall results were summarized in the Tab 1. The table shows both averages of maximal values for each configuration. It should be mentioned, that in many cases, various types of failures occurred in the same configuration. Therefore, only the prevailing type of failure is displayed in the table below. Unmarked values refer to an external thread stripping failure.

Due to large deformations, it can be assumed that the effective length of engagement did not remain constant during the testing which puts some challenge into computational verification. It can be easily shown, that results in the Tab. 1 regarding same geometry sets are not exactly proportional to the shear strength of the material as expected, especially in cases, where the thread stripping occurred on bolt in one case but in hole in the other.

Tab. 1: Average of measured values of joint strength for several geometries

Thickness	2 mm			3 mm	
Material	S235JRG	S355J0	DOCOL 1200M	S235JRG1	S355J0
M5	6 700* N	8 110 N	12 630 N	11 270* N	12 720 N
M6	8 420* N	9 140 N	15 000 N	13 420* N	15 250 N
M8	9 580* N	11 600** N	16 720* N	14 200* N	18 510** N

** failures with dominant internal thread stripping*

***failures with dominant sleeve breakage*

5 Conclusion

There are some facts, which are clearly apparent from the results. It is obvious, that thickness has a major influence on the joint strength. Since increase of thickness is associated with an increase of effective length of engagement, it can be assumed that the strength is a function of a shear area in this case as well, which is correspondence to Alexander's theory [1].

However, it can be observed from Tab. 1, that same geometry configurations (as in M5, 2mm thickness, S355J0 a DOCOL1200M) associated with an external stripping (taking the same reference material of the bolt into account) provide quite distinct values. Therefore Alexander's theory cannot by simply extended to this case and requires some additional variables.

In addition, some configurations did break in very a different manner. The failure, where the sleeve separated from the base material brings new uncertainties to the estimation of strength of joints produced by the thermal drilling. There are possibilities to follow this study with different types of constraints. Which would allow evaluation of the sleeve failure. Measurements could be carried out on a different sets of specimen thicknesses, however choice of configurations presented in this paper were believed to be most effective for the technology.

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