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# AN ECONOMIC APPROACH TO IMPROVE THE STRENGTH OF SEALED THREADED FASTENERS

***The paper presents the method of reducing costs and increasing the strength of threaded joints, which are currently used in almost every field of human activity. The results of economic analysis of existing methods for securing such joints are presented. Experimental research on the relation between thermal treatment and strength of adhesively sealed joints was conducted. Comparison of minimal torque required to loosen the joints sealed with three types of anaerobic adhesives was measured before and after the described treatment. The results show possible application of the method and economic grounds for applying the technique for increasing strength of existing joints for some adhesives only.***

***Keywords:*** *economic analysis; cost reduction; threaded joints; adhesive joints; loosening torque; heat treatment.*

**Якуб Шабельскі, Яцек Домінчук**

# ЕКОНОМІЧНИЙ ПІДХІД ДО ПІДВИЩЕННЯ ЯКОСТІ ГЕРМЕТИЧНИХ РІЗЬБОВИХ З'ЄДНАНЬ

***У статті представлено метод зниження витрат за одночасного підвищення якості різьбових з'єднань, які на сьогодні використовуються практично в усіх сферах життєдіяльності. Представлено результати економічного аналізу існуючих з'єднань. Проведено експеримент для виявлення зв'язку між термальною обробкою та міцністю різьбового з'єднання. Проведено порівняння мінімального скручування герметичних різьбових з'єднань трьох типів анаеробних клеїв. Результати порівняння доводять застосовність досліджуваного методу, надано економічне обґрунтування застосування техніки підвищення сили з'єднань для деяких видів клеїв.***

***Ключові слова:*** *економічний аналіз; зниження вартості; різьбові з'єднання; клейові з'єднання; момент відвертання різьбового з'єднання; термальна обробка.*

***Табл. 1. Рис. 6. Літ. 12.***

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# ЭКОНОМИЧЕСКИЙ ПОДХОД К ПОВЫШЕНИЮ КАЧЕСТВА ГЕРМЕТИЧЕСКИХ РЕЗЬБОВЫХ СОЕДИНЕНИЙ

***В статье представлен метод снижения затрат и одновременного повышения качества резьбовых соединений, которые сегодня используются практически во всех сферах жизнедеятельности. Представлены результаты экономического анализа существующих на сегодня соединений. Проведён эксперимент для выявления связи между термальной обработкой и прочностью резьбового соединения. Проведено сравнение минимального закручивания герметических резьбовых соединений трёх типов анаэробных клеев. Результаты сравнения доказывают применимость исследуемого метода, дано экономическое обоснование применения техники повышения силы соединений для некоторых видов клеев.***

***Ключевые слова:*** *экономический анализ; снижение стоимости; резьбовые соединения; клеевые соединения; момент отворачивания резьбового соединения; термальная обработка.*

## 1. Introduction

Screw threads are present in almost every aspect of modern life. This specific structure due to its simple manufacturing and low cost of assembly can be found in a

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number of applications, starting with Hubble Telescope, through household equipment, at human prostheses finishing. The geometrical shape of thread is helicoidally shaped cut or formed structure inside a cylinder (internal – female thread) or outside rod or other elements (external – male thread). Different shapes of threads are manufactured for different applications (square, triangular, trapezoidal and other). Some other dimensions also vary between specific threads (thread angle, pitch). Number of standards were prepared in many countries to describe threads. Nowadays, during the globalization era mainly the following types are manufactured and used: ISO (International Organization for Standardization), together with two others: The British Standard Pipe (BSP) and National Pipe Thread Taper (NPT).

From the functional perspective, threads allow providing two contrary features into products. On the one hand threaded joint changes the rotary movement of screwing in or out into the linear movement of screw going up or down, which is adapted in machines and manufactured products as a solution for movement transformation. On the opposite, it prevents linear motion of joined elements if rotary motion is not applied (joins parts or elements together). The second feature is used in fastening elements for quick and easy assembly and/or disassembly.

To increase fastening properties of such a joint, sealants are used between internal and external thread to prevent loosening the joint and leakage from shock and vibration (when joint are prepared to fasten, for example, liquid or gas feeding pipes). Early methods for fastening threads were based on application of lead or its oxides, which after discovering of their toxic nature, both during application and in use, made them unsuitable especially when sealing pipes for transport of drinking water (Valitsky, 2008). Other solutions for preventing leakage were paints and dopes applying on the thread evaporated leaving solid seal. Unfortunately, such a seal was too rigid and therefore not resistant to dynamic character of joints (hydraulic systems) – it cracked. Another type of thread protector but different than above described is a Teflon tape, which doesn't seal the thread but due to antifriction properties – allows more turns to be taken on a tapered fitting. The most important so-called threadlocker thought is the group of anaerobic adhesives. Modern threadlocking adhesives are in a liquid or semisolid (stick) form. They remain uncured (liquid or semi-solid) in presence of air and cure when it is absent (Lescarbeau, 2010). Due to slow curing process assembled threads can be adjusted without breaking the seal inside.

To enhance their performance, anaerobic formulations have been developed for applications exposed to high temperatures, oil contamination or designed for less active surfaces. Such solution has many advantages: resistance of joint to vibrations, chemical resistance of adhesive to standard technical liquids and gases and non-toxicity which allows application in food industry and heat resistance even up to 230°C (Loctite, 1998).

The main reason behind conducting the research below is the introduction to answering the issue of cost-effectiveness of such solution. As adhesives manufacturers state, thread protection significantly decreases the overall cost of production as regular (that is non-expensive) nuts and bolts can be used instead of expensive joining solutions. The compared overall cost (based on German costs) of applying an adhesive threadlocker compared to using a more expensive ribbed flange bolt is presented in first two rows of Table 1 (Loctite, 1998).

*Table 1.* **Cost comparison of standard method of securing threaded joint and reason for conducting research** *(Loctite, 1998)*

| Method | Material cost, % | Assembly cost, % | Total cost, % |
|---|---|---|---|
| Ribbed flange bolt | 130 | 65 | 118 |
| LOCTITE adhesive @ standard bolt | 100 | 100 | 100 |
| Anaerobic adhesives after heat treatment @ standard bolt | ? | ? | ? |

Although the cost calculation doesn't cover cleaning and degreasing bolts and nuts (as it can only be calculated for series production) – still observed cost of using other technological solutions is almost 1/5 higher than the thread locking using adhesives. The given research was conducted in order to fill the last row of the table. This paper presents the first stage of a more complex research that is the evaluation of border torque of threaded joint that is to measure the torque required for loosening the joint (of the same dimension) before and after heat treatment. The final research will be completed by a detailed economic analysis of costs for the introduction of such a processing method. The analysis will cover points presented in Table 1 – material cost (including cost of adhesives) and assembly costs (including the overall costs of heat treatment) and present the total cost of applying different heat cured anaerobic adhesives for threadlocking. Further, one can examine if it is possible to apply smaller nuts and bolts, which after heat treatment of adhesive can withstand the same torque as regular size nuts and bolts to decrease the cost of materials even more.

**2. Heat treatment for increasing the strength of anaerobic adhesives joints**

Anaerobic adhesives applied for threadlocking and sealing are affected by heat in many different ways, depending on which stage (preparing, curing, using), how long and what amount of heat were they exposed to. Some of these influences can result in positive way – for example sealed thread requires more torque to breakloose – it is locked and sealed better. One of 3 main situations when temperature of adhesive joint (adhesively locker thread in this case) has to be considered is heat strength. It is the phenomenon of decrease of strength of joint when it is tested in increased temperature (Szabelski, 2013). The main explanation of this effect is the degradation of bonds within the adhesive chemical structure. The border temperature for which no change in strength of joint is observed is different for various adhesives and depends on the chemical structure of an adhesive and especially on specific add-ons applied in its preparation. This temperature can be 40°C, sometimes more than that. Above this border temperature – significant and most of times linear decrease of total strength of joint can be observed. Hot strength of examined adhesives is presented in Figure 1. As it is presented – one of adhesives was designed and tested to be able to work down to -50°C.

In the above case, the influence of temperature is considered without pointing the time of exposure. Therefore, this effect considers only temporary increases of temperature during the running time of a machine/product. An engineer must be aware of that fact and design a joint to be able to work: all the planned time, in set conditions, without danger of breaking the joint and damaging the machine/product or even worse – the operator or user. Specific adhesives used in the research to be presented below, show decrease up to 20–40% of initial strength when exposed to temperature of 150°C (Technical Data Sheets). Expanding the short time influence of temperature on joint by time factor — the new effect is observed — heat aging. By definition it is the change of overall joint strength after long exposure to temperature. Time of such an exposure is measured in hundreds or even thousands of hours and can correspond to constant working conditions of machine or product. Surprisingly it was observed that for some adhesives long exposure to temperature can increase strength of joint (Technical Data Sheets).

The below examined anaerobes show all 3 possible reactions: increase, no effect and decrease of strength after 1000—5000 hr of exposure to 100—150°C. These effects take place when joints are already assembled and adhesive is fully cured.

But heat can also influence the adhesive on the stage of curing the adhesive — that is during the preparation of a joint. Heat treatment of uncured adhesive joint can be one of methods for increasing final strength of joints. Other methods base on specific methods for preparation surfaces of bonded elements. Such a modification increase energetic properties of surface layer. Some of those operations are: chemical treatment (ozoning (Klonica, Kuczmaszewski, Kwiatkowski, Satoh, 2013), degreasing agent (Rudawska, 2012)), mechanical processing (Dominczuk, Szabelski, 2011) or introducing coatings (for example, $SiO_2$ and $SiO_2$-$TiO_2$ (Bienias, Surowska, Stoch, Matraszek, Walczak, 2009)). Some of the presented methods allow relatively cheap improvement strength of these joints. To forecast this strength on the stage of designing a product the research can be conducted using neural networks (Dominczuk, Kuczmaszewski, 2008) or Finite Elements Method — FEM (Rudawska, Debski, 2011; Kuczmaszewski, Wlodarczyk, 2006).

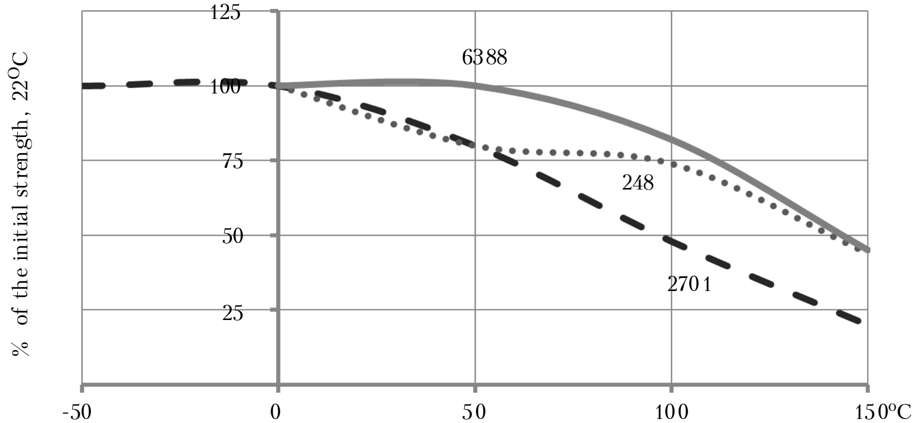


*Figure 1.* **Hot strength of examined anaerobic adhesives** *(Technical Data Sheets)*

### 3. Experimental research

The main objective of the research is to examine if heat treatment of screw/bolt joint sealed using anaerobic adhesive results in increasing torque needed to loosen threaded joint. Such an expected increase can justify heat treatment as an economic operation for improving overall strength of thread joints. If the results show significant increase of strength — application of more expensive adhesives or generally larger quantities of adhesive — will not be necessary due to an economic factor.

As adhesive manufacturers already developed a number of adhesives for threadlocking and thread sealing also other types of adhesives were examined during the research. 3 Henkel Loctite adhesive were compared: threadlocker 248, threadlocker with sealing properties 2701 and the adhesive for bonding cylindrical elements 638. 2 of them are liquids, 1 is wax-like semi-solid in self-feeding stick applicator. M16 bolts and nuts were selected for research. Fasteners were obtained in zinc coated state. Bolts and nuts were cleaned using Loctite 7063 cleaner and degreaser and examined for visual defects of thread before bonding. After that, bolts thread was covered with adhesive focusing on covering it carefully all over internal diameter of bolt and on length exceeding the length of nut. For each adhesive the samples were prepared: half of the samples cured 48h in 20°C, other half was exposed in furnace to 50°C for 2h and spent remaining 46h in 20°C (Figure 1).

*Figure 2.* **Some test samples after sealing with anaerobic adhesive** *(Authors' development)*

Test stand was based on MTS Bionix Servohydraulic Test System which was used to measure torque required to breakloose the joint. Specially designed fixture based on socket wrench separated sockets allowed placing bonded nut and bolts in cylindrical grip of tensile machine and conducting torsional measurements. MultiPurpose TestWare was used for designing detailed procedure for the research. The program for testing the sample was build using MPT tile drag & drop interface presented in Figure 3.

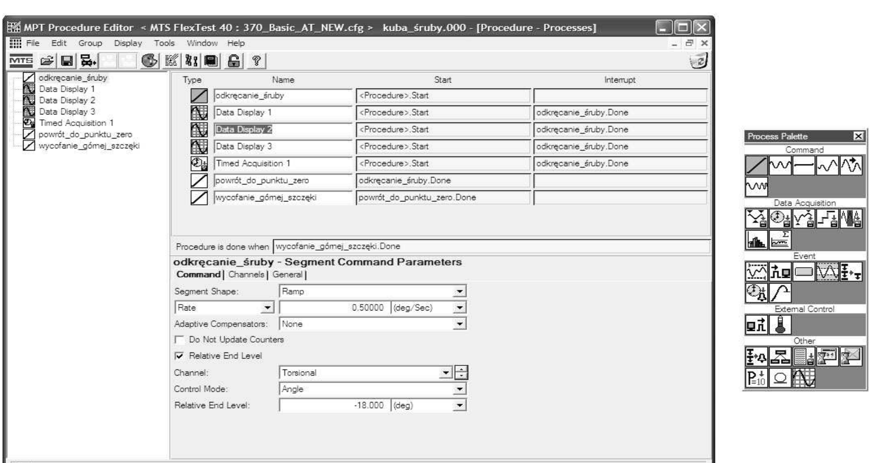


*Figure 3.* **MPT Experiment Procedure Editor with prepared program for measuring a single sample** *(Authors' development)*

Every step of experiment needs to be planned and carefully programmed picking the correct tiled modules from process palette and placing them in correct order in Procedure Editor Window. The finishing step needs to be defined after which the whole sample testing procedure finishes.

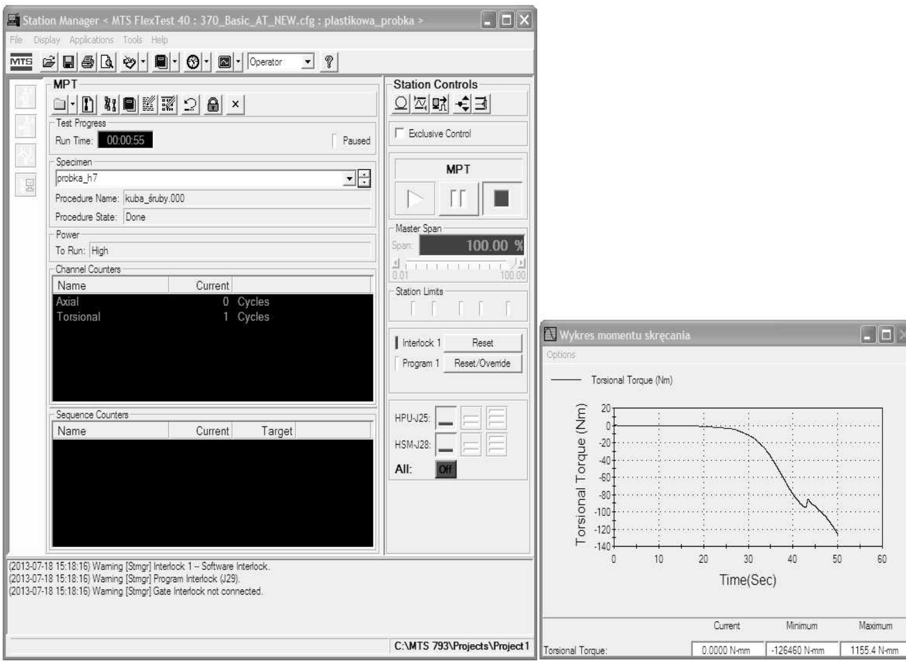


*Figure 4.* **A graph of one of the samples** *(Authors' development)*

Also for data collection modules – the interrupt command must be defined. During the presented experimental research bolts were unscrewed and torque of loosening was measured. The rate of turn and end level of turn were set. Measured data was presented online on computer screen and collected to CSV (comma-separated values) format file for further processing as it was programmed in prepared procedure (Figure 4). Torque on graph is negative due to loosening the nut by turning it counter-clockwise.

The result obtained in the research was quite surprising as only one of adhesives (2701) presented the increase of torque after heat processing. The results of measuring loosening torque before and after processing for this specific adhesive are presented in Figure 5. Analysing Technical Data Sheet of 2701 (Technical Data Sheets) one can find out that the adhesive was already tested for cure speed vs. time but for steel pins/collars case only. Surprising is the fact that manufacturers research (for before mentioned type of joint) didn't show any difference in final strength between joint cured in room temperature and samples after heat treatment. The only difference (as product card states) is in time of reaching 100% of the final strength. Curing in 40°C allows shortening this time from 24h to about 6h (comparing to curing in room temperature), but nevertheless, no strength increase was observed. For the authors' the presented research on threaded joints that increase reached 25%.

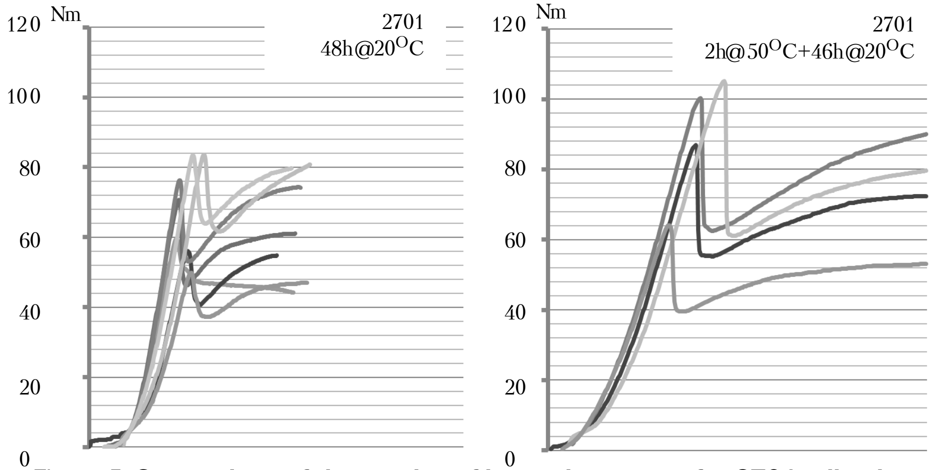


*Figure 5.* **Comparison of time series of loosening torque for 2701 adhesive without (left) and after (right) heat treatment** *(Authors' development)*

The possible explanation can probably be found in type of bonded materials. Data sheet describes steel joints and research samples (bolts and nuts) were zinc coated which although protect thread from corrosion but results in creating not as strong adhesive joints.

Two other adhesives (248 and 638) were not affected by thermal processing. The obtained results were almost equal to non-heated samples. The detailed results of comparison are presented on Figure 6.

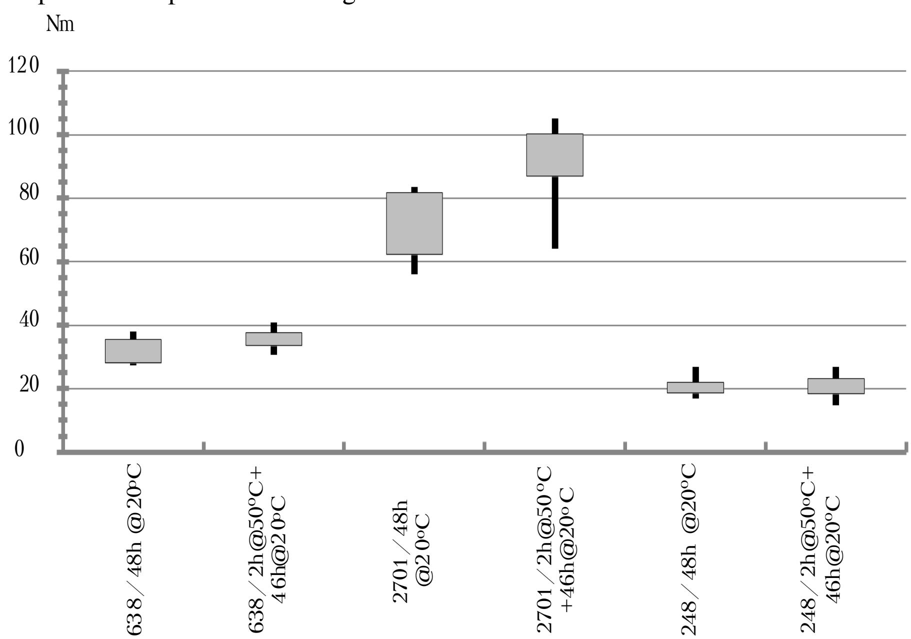


*Figure 6.* **Measured loosening torque values (Nm) of all examined adhesives before and after heat treatment** *(Authors' development)*

**4. Conclusion**

The results of the research proved that there exist such anaerobic adhesives that can be processed thermally in order to obtain higher strength of joints — threaded joints secured using mentioned adhesives specifically. As the increase of loosening torque is significant (25%) the method can be applied in industry everywhere where the application of more expensive (but stronger) adhesive is uneconomic. Although the key question of complete cost of such a processed joint remains unresolved. This research will be continued in order to describe two important aspects of application of threaded joints after heat curing: the overall, total cost of preparation of joint threadlocked using that method and possible utilization of smaller dimension elements (nuts and bolts) which after heat curing may be able to withstand the same torque as bigger ones but not heat treated.

Research on adhesives not designed for threadlocking (but for bonding cylindrical elements) but used for sealing threaded joints proved that such adhesive can be successfully used in such an application.

As threaded joints are widely used in machine building or transportation their further examination seems to be necessary. Conducted research can also be continued in several other directions in future. Although not all of the examined anaerobic adhesives were found to be susceptible to heat processing during curing and keeping in mind that only 3 adhesives were selected for the research — it is clearly not enough to answer the question but enough to treat the research as a beginning of bigger research on complex explanation of topic. More adhesives should be tested to achieve it: not only threadlocking adhesives but also adhesives designed for other purposes. Such an approach would result in creating an overview of adhesives and heat influence on strength of threaded joints sealed using them. The next problem is temperature ranges and exposure time. One can continue the presented research in order to cover all usable combinations of temperatures in which adhesives were additionally cured and time of exposure. This would answer the question if there exists some border time of exposure after which no increase of strength of cured adhesive is observed and further exposure is pointless. Similar — if there exits some border temperature of curing the threaded joints sealed with anaerobic adhesives above which no increase is observed. Different results could be obtained if a joint is exposed to a temperature below 00C or tested in thermal shock chamber (where normal, variable exploitation conditions can be simulated, for example temperature variation between -200C and +500C). The presented research focused on strength side of threaded joint not considering sealing issues. Measurements of for example pressure of compressed air transported by thread pipes fastened using adhesive could answer the question of influence of heat curing on sealing properties — defining the border pressure which such a joint withstands. This and other questions leave much room for further research, some of which the authors plan to conduct in the near future.

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Стаття надійшла до редакції 05.08.2013.