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EFFECT OF KINEMATICS OF THE PROCESS OF SCREWING ON A QUALITY OF THREADED CONNECTIONS

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ВЛИЯНИЕ КИНЕМАТИКИ ПРОЦЕССА СВИНЧИВАНИЯ НА КАЧЕСТВО ГЛАДКО-РЕЗЬБОВЫХ СОЕДИНЕНИЙ

Purpose. Research the influence of the process parameters on the quality thread connections, notably, thread formation axial force on the opposite sides of the roots. Determination of the thread-formation axial force for the spaced threads.
Design/methodology/approach. In a paper it is shown, that action of uncompensated thread formation axial force increases the defects and imperfectness of the strengthened layer. Proposed the theory about changes in the traditional self-stretching thread-formation, method of the implementation the process with constant axial force. The external axial load must be equal to the largest axial component force of the thread-formation. The method uses the slip-line method with a model taking into account the interaction between two consecutive formed threads and enables the mean pressure on the thread flank to be obtained as a function of the formed thread height. From these results and a knowledge of the forming screw end geometry, an analytical method is proposed for the maximum axial force, the physical phenomena of the displacement of material in the tapping process is illustrated and the significantly influential parameters highlighted.
Findings. This study proposes an analytical model based on a previous study concerning radial penetration of a rigid acute wedge into a perfectly plastic material. An experimental study seeks to determine the optimal lead hole on the work piece for an M8 screw. The experimental results are compared favorably with the results of the analytical study in order to validate the forming screw model.
Originality/value. It is shown the influence of the geometrical parameters of the thread forming screw and of the work-piece on the axial force, and the influence of the process parameters on the quality of threaded connections. This sets limits on the forming axial force and conserves a sufficiently well formed thread shape for good stripping resistance. The experimental results are compared favorably with the results of the analytical study in order to validate the forming screw model.
Keywords: Self-Drilling Thread-Forming Screws, screw connections, force of the thread-formation.

Screw connections are the most labor-intensive and the most difficult to automate. In industry and construction, Self-Drilling Thread-Forming Screws are used. Self-cutting screws drill their own tapping hole to close tolerances and from their mating themselves. The specially formed and stamped drill point prevents any drifting around the surface of the component allows rapid spot drilling. There’s no longer any need to centre punch the drilling point? No drilling or thread-cutting tools needed, no additional securing elements needed. Thanks to this properties self-cutting screws can be worked quickly and cheaply. Savings up to 50% are possible compared with conventional tapping screws. Their effectiveness is determined by eliminating the need to pre-drill holes in joined parts or extrusion of the threads and accurate basing of the screw in the hole under the thread formation.

In general, tapping screws permit rapid insertion because nuts are not used and access is required from only one side of the joint. Mating threads created by these tapping screws fit the screw threads closely, and no clearance is needed. The close fit usually keeps the screws tight even when subject to vibrations.

Tapping screws are used in steel, aluminum, die-castings, cast iron, forgings, plastics, reinforced plastics, and resin-impregnated plywood. This method provides a high yield, higher quality of connection, increase of static and fatigue durability of screw-threads in comparison to screw-threads that are cut.

The main criterion of efficiency of threaded joints fastening is strength. Breakage of threaded parts in most cases arises from fatigue that is associated with the action of variable stresses effect. Static strength of threaded joints obtained through self-tightening with a tension value of 30% to 100% is higher than that of the joints threaded by 1, 5-2 times, while the cyclic durability is lower.

Based on the analysis of the factors that determine the performance of threaded elements in the conditions of cyclic loading, it is known that structural defects constitute approximately 11%, process defects – 47%, material defects 4% and defects that occur during the operation – 38% [1]

We know about the impact of external axial force on the axial symmetry of defamation in magnitude and gradient on opposite sides of the root and depressions forming in its profile that indicates its crucial part in shaping the final pattern of stresses in the zone of maximum deformation, which is also a zone of stress concentration [2], [3]. Fig. 1

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shows a picture of isoskleres (lines connecting points of equal hardness or softness of material) in the axial section of the thread.

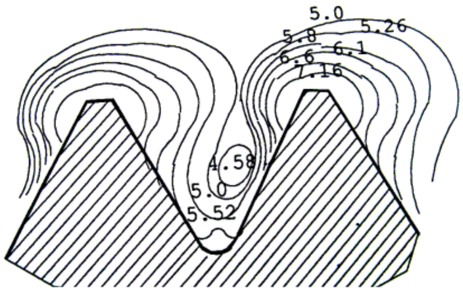

Fig. 1. Picture of isoskleres

The hardness of the material in Pa (figures on the curves indicate the level of micro hardness, the arrows indicate the direction of screwing of the screws): a - by screwing in the hole with forced feed; b - using self-tightening method [4], [5]. The asymmetric flow of the metal indicates the impact of uncompensated axial force that imposes changes on compressive remnant tension. On the photo, (Figure 2, 3), the asymmetry of the formed profile is shown; both the asymmetry of the peaks like «craters» and the distortion of form of the groove area occurs here.

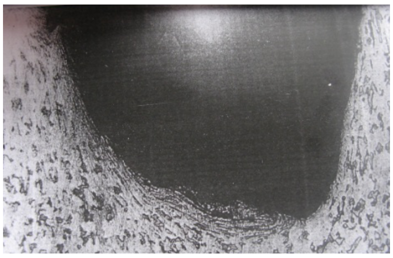

Fig. 2. Profile Photo of the groove carving area of the screw-thread that is formed at insufficient axial force (150 and 100 - fold increase)

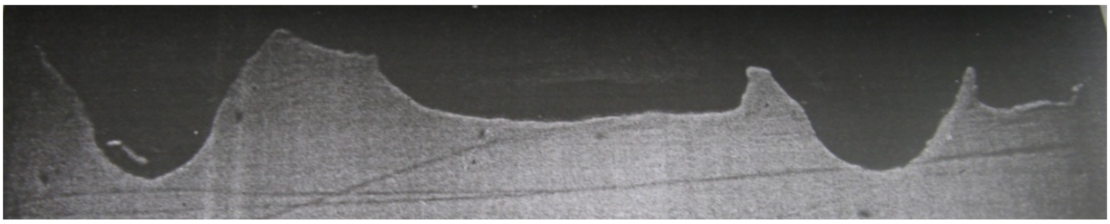

Fig. 3. Profile Photo of the second coil of screw-thread that is formed at insufficient axial force (100 - fold increase)

The action of uncompensated force increases the defects and imperfectness of the strengthened layer and imposes compressive stress on the stretching stress in the grooved area, resulting into their relaxation. It neutralizes the positive effect of plastic deformation and reduces the quality of the formed screw-thread.

Application of an axial force in the thread-formation by the Self-Drilling Thread-Forming Screws leads to approaching methods of drilling and rolling. The screw has a high strength and stiffness, defined length and diameter, and one-off use can significantly change the parameters of drilling in comparison to the traditional process.

It is proposed to apply the Self-Drilling Thread-Forming Screws with a determinate load. This makes it possible to offer a compromise method of assembly using self-drilling screws, to develop a range of automated devices implementing this method, and implement a progressive method of assembling in industry and construction. Drilling parameters of the self-drilling screws in this case, match the parameters of the thread-formation ifs fit into the gap between the allowed values of cutting parameters during drilling.

These considerations speak about correctness of changes in the traditional thread-formation method on the implementation process with a constant axial force. The external axial load must be equal to the largest axial component force of the thread-formation.

The main work of the formation of the threads is performed by the walls of the screw. Getting analytical dependence for radial force of the thread-formation gets down to the determination of the contact stresses and planes.

Features of flat plastic flow have qualities that allow us to find the solution using graphical method. The method uses the slip-line method with a model allows us to calculate contact stresses and deforming forces. The type of plastic area and its field of slip lines depend on the pressing scheme which is determined by the geometry of the lead-in part of the thread-forming part, which may be conical or cylindrical.

This can be done using a solution of the classical problem of the theory of plasticity about immersion of a hard wedge into a rigid plastic region, this building slip-lines (Figure 4). The solution for rough wedge perfectly smooth on that line sliding constructed taking into account the angle of friction δ, ie

$$\Theta = \Theta - \delta = \frac{\pi}{2} - (\gamma + \beta). \tag{1}$$

Figure 4 shows that with increasing δ increased free limits 2.1-3.0, which leads to the expansion of 2.1-3.0-2.0. This depth introduction wedge t with increasing δ are reduced. According to the theory Sokolovsky angles θ_0 and β are independent of δ. The figure 4 depicts the variation of co-efficient of friction with respect to semi wedge angle. With the increase of wedge angle the normal force and tangential force increases. But, the variation of normal force is very high. Again, it is clear that normal and tangential force increase with increase of depth of indentation. But wedge surface pressure decreases with the increasing wedge angle.

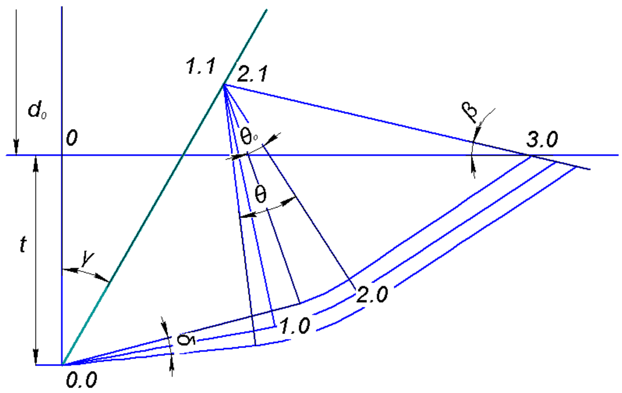

Fig. 4. The description of slip-line field for wedge indentation

For screws with a wide groove the formula for determining $P_{ax.}$ is obtained on the basis of the solution of the task of theory of plasticity about the immersion of a hard wedge in a hard and rigid plastic area. Method simulates any combination thread-formation conditions (conditions of friction, tightness, precision connection) for any combination of the profile height and width of the thread groove.

$$P_{ax} = 2kS\left[\frac{\pi}{2} - \gamma + \beta + \frac{\cos\delta}{\cos\gamma}\cdot\cos(\gamma - \delta)\right]\tan\delta\cos\gamma\sin\omega\ . \tag{2}$$

Where: $P_{ax.}$ - axial force,
k - plastic constant,
γ - the semi-wedge angle,
S - the area of the contact surface,
δ - the angle of friction,
ω - the angle of ascent of the spiral.

The magnitude of effort needed to turn the Thread-Forming Screws, is proportional to instantaneous area of contact of this turn with the work-piece of IAC. The analytical calculation of the IAC during thread-formation requires solving the problem of intersection of space bodies of complex curved shapes, approximate methods for determining IAC does not always provide sufficient accuracy of calculations. Calculating the IAC in thread-formation is possible by geometric 3D-modeling process in T-FLEX CAD 3D. As a result, on the 3D-model of the work-piece there are imprints of coils of screw, whose area equals to the IPC during thread- formation (Fig. 5).

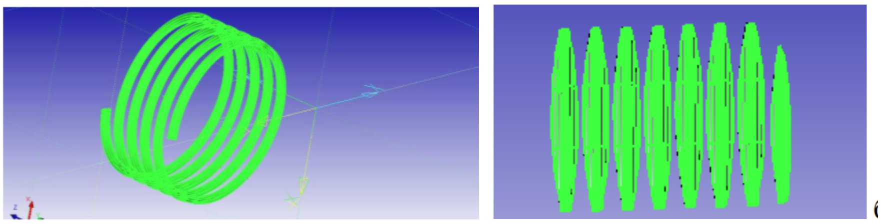

Fig. 5. Determination of IPC using T-FLEX CAD 3D

The experimental study presented in this paper is divided into two parts. The first concerns the thread forming process and shows the influence of the geometrical parameters of the thread forming screw and of the work-piece on the axial force, and the influence of the process parameters on the quality of threaded connections. The second part concerns the tightening process. A compromise can be proposed for the choice of the lead hole diameter, which is the most important parameter to be considered in order to keep a reasonable forming torque while obtaining threads deep enough to avoid stripping problems. An original experimental device is used to enable generate the tightening torque according to the preload applied inside the assembly.

Self-drilling screws for the application fixing to steel, intended for drilling and tapping into layered or unlayered steel shall be type ASD, BSD or CSD. TYPE ASD and BSD screw have spaced threads and type CSD screws have threads of UNC machine screw diameter-pitch combination with a 60 degree basic thread form. Lead hole for thread traditionally defined on the ground of maintaining the constancy of volume before and after plastic deformation, the various clarifications and limitations that take into account the conditions of friction as strength, size tolerances. All these specification necessary to reduce the likelihood for overflow profile of the thread. In case of the threads of UNC and UNF machine screw lead hole for thread defined not only the constancy volumes before and after deformation, but the conditions of similarity thread profiles on the screw and in the hole. Spaced threads forming the thread in the hole of a different profile, so you can not apply the conditions are similar. Spaced threads form the thread in the hole of a different profile, so you can not apply the conditions of analogy.

Since the condition for preserving the constancy of volume before and after plastic deformation abideth in strength, it is necessary to determine the geometric parameters of the established profile, such as raising the height of the deformed material. This can be done using a solution of the classical problem of the theory of plasticity the penetration of a smooth rigid wedge into a semi-infinite mass of rigid/perfectlyplastic material. Based on the Figure 6 calculated value of the diameter of lead hole for thread $d_0 = (d-2t)/2+\Delta t$. It depends on the outside diameter d of the screw and of indentation, the value of which is easily determined depending on the desired size of the profile height or taken from the drawing-rigid plastic region.

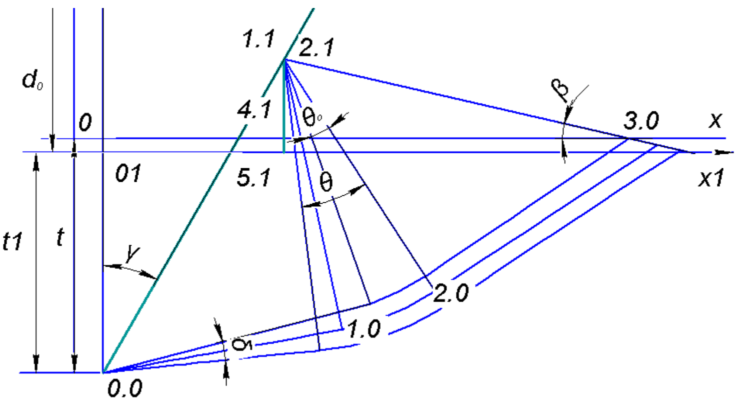

Fig. 6. The scheme of the determination of the correction

Method of determining d_0 is based on the classical problem of the theory of plasticity, such as solving the problem of the penetration of a smooth rigid wedge into a semi-infinite mass of rigid/perfectlyplastic material, to simulate any combination conditions of thread-formation (conditions of friction, tightness, precision connection) for any combination s profile height and width of the thread pitch.

This study proposes an analytical model based on a previous study concerning radial penetration of a rigid acute wedge into a perfectly plastic material. The method uses the slip-line method with a model taking into account the interaction between two consecutive formed threads and enables the mean pressure on the thread flank to be obtained as a function of the formed thread height. From these results and a knowledge of the forming screw end geometry, an analytical method is proposed for the maximum axial force, the physical phenomena of the displacement of material in

the tapping process is illustrated and the significantly influential parameters highlighted. An experimental study seeks to determine the optimal lead hole on the work piece for an M8 screw. This sets limits on the forming axial force and conserves a sufficiently well formed thread shape for good stripping resistance. The experimental results are compared favorably with the results of the analytical study in order to validate the forming screw model.

Анотація. *В статті наведені результати теоретичних та експериментальних досліджень різьбоформування саморізальними різьбоформуючими гвинтами під дією постійного осьового навантаження. Пропонується заміна традиційного метода різьбоформування самозатягуванням на здійснення процесу з постійною осьовою силою. Для визначення зусиль, діючих при різьбоформіруванні гвинтами з широкою канавкою, застосовується метод ліній ковзання і метод 3D–моделювання для визначеннямиттєвої площі контакту при різьбоформуванні. Порівняльні експериментальні дослідження, що проводились для підтвердження аналітичної моделі різьбоформування гвинтами з широкою канавкою, дали позитивні результати.*
Ключові слова: саморізальні різьбоформуючі гвинти, різьбоформування,осьова сила, гладко-різьбове з'єднання, метод ліній ковзання.

Аннотация. *В статье приведены результаты теоретических и экспериментальных исследований резьбоформирования саморежущими резьбоформирующими винтами под действием постоянной осевой силы. Предлагается заменить традиционный способ резьбоформирования самозатягиванием на проведение процесса с постоянной осевой силой. Для определения усилий, действующих при резьбоформировании винтами с широкой канавкой, применяется метод линий скольжения и метод 3D–моделирование для определения мгновенной площади контакта при резьбоформировании. Сравнительные экспериментальные исследовани, проведенные для подтверждения аналитической моделия резьбоформирования винтами с широкой канавкой, дали положительные результаты.*
Ключевые слова: саморежущие резьбоформирующие винты, гладко-резьбовые соединения, осевая сила резьбоформирования, метод линий скольжения.

Библиографический список использованной литературы

1. *Савченко В.А.* Повышение ресурсных характеристик резьбовых соединений деталей авиационных двигателей за счет оптимизации технологических параметров: Дис ... канд. техн. наук: 05.02.08.– М., 1990.– 165 с.
2. *Лукашов В.А.* Разработка и исследование способа формообразования мелкоразмерных тугих резьбовых соединений крепежными шпильками в высокопрочных Al сплавах: Дис ... канд. техн. наук: 05.02.08. – М., 1990. – 183 с.
3. *Петриков В.Г.*, Власов А.П. Прогрессивные крепежные изделия. М.: Машиностроение, 1991. 256 с.
4. *Механизация* и автоматизация сборочных работ на машиностроительных предприятиях /Б.М. Арпентьев, *А.С. Зенкин*, А.Н. Куцин. – К.: Техніка, 1994. – 232 с.
5. *Березин С. Я.*, Романова Л. С. Асимметрия выдавливаемых профилей при образовании гладко-резьбовых соединений// Учёные записки Забайкальского государственного университета. Серия физика, математика, техника, технология –2013 – С.7-13.

References

1. Savchenko, V.A. (1990), Improving resource characteristics of the threaded connections of parts of aircraft engines by optimizing the technological parameters: Dis ... Cand. tehn. Sciences: 05.02.08. Moscow, Russian.
2. Lukashov, V.A. (1990), Development and research of a methods of forming small-sized tight threaded joints fastening pins in high strength-Al alloys: Dis ... Cand. tehn. Sciences: 05.02.08. Moscow, Russian.
3. Petrikov, V.G. and Vlasov, A.P. (1991), *Progressive fasteners Engineering*, Moscow, Russian.
4. Arpentiev, B.M., Zenkin, A.S. and Kuzin, A.N. (1994), *Mekhanyzatsiya i avtomatizatsiya sborochnikh rabot na mashinostroitelnikh predpriyatiyakh* [Mechanization and automation of Assembly works in machine-building enterprises], Tekhnika, Kyiv, Ukraine.
5. Berezin, S.Ya. and Romanova, L.S. (2013), Asymmetry of Structural Extrusion When Forming Smooth-Threaded Connections, *Uchenye Zapiski of Zabaikalsky State University*. Series Physics, Mathematics, Engineering, Technology, pp. 7-13.

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