What U.S. Export Markets are Rising?

Germany is dancing to a different waltz than Canada and China. U.S. exports of cars to Germany increased 8.2 percent from 2015 to 2016 and totaled $6.7 billion. Germany made up for 11.4 percent of the U.S. car export market in 2012 but today accounts for 12.4 percent. U.S. exports of cars to Germany dipped in 2013 but have grown annually and consecutively since then.

South Korea, though a smaller US export market than Canada, China and Germany - making up only 3 percent of the market - has increased 23 percent in their imports of U.S. cars. U.S. exports of cars to South Korea totaled $1.6 billion in 2016 and have increased market share by nearly 2 points since 2012.

U.S. Exports of Cars (HS 8703)

Country of Destination	2016 JAN to DEC		2015 JAN to DEC		Volume Change	
	FOB Value US$	%	FOB Value US$	%	FOB Value US$	%
CANADA	14,590,093,555	27.12	14,759,969,364	26.67	-169,875,809	-1.15
CHINA	8,862,548,013	16.47	9,143,266,008	16.52	-280,717,995	-3.07
GERMANY	6,655,552,033	12.37	6,149,682,896	11.11	505,869,137	8.23
MEXICO	3,618,921,365	6.73	3,119,908,918	5.64	499,012,447	15.99
SAUDI ARABIA	2,833,541,569	5.27	3,845,809,912	6.95	-1,012,268,343	-26.32
UNITED KINGDOM	2,278,377,183	4.23	2,172,282,308	3.93	106,094,875	4.88
UNITED ARAB EMIRATES	1,946,339,350	3.62	2,587,942,457	4.68	-641,603,107	-24.79
SOUTH KOREA	1,587,373,466	2.95	1,289,032,629	2.33	298,340,837	23.14
AUSTRALIA	1,418,381,272	2.64	1,766,035,296	3.19	-347,654,024	-19.69
KUWAIT	530,582,156	0.99	653,155,513	1.18	-122,573,357	-18.77
Total:	44,321,709,962	82.37	45,487,085,301	82.19	-1,165,375,339	-2.56
General Total:	53,807,477,416	100.00	55,343,418,725	100.00	-1,535,941,309	-2.78

U.S. Car Import-Export Trade Trend for the Future

U.S. imports of cars don't look to be slowing down any time soon. As the world's largest consumer of vehicles, the U.S. import market of cars has continued to grow in 2016. The leading trade partners for U.S. car imports are Canada, Japan and Mexico, though looking at a five-year trend, the growing players in the U.S. import market are Mexico, South Korea and the United Kingdom, all of which could be a rising force for the U.S. car trade in the coming years.

The U.S. export market for cars is in a bit of a slump, but that doesn't mean there isn't growth with some nations. Including Germany and South Korea which have increased their imports of U.S. cars in the last few years and increased in overall market share.

For the future, U.S. imports of cars continuing to rise could be a safe bet and select export markets will continue to rise. We will see what 2017 has to offer. ■

Fastener Expert **101** Series:

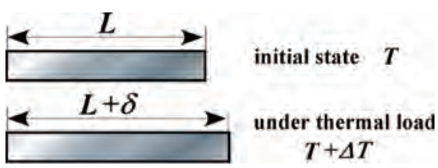
Behavior of Threads Under Thermal Load-Predicting the Variation of Axial Force

by Toshimichi Fukuoka

Introduction

The loosening due to thermal load in high/low temperatures and the plastic deformation of bolted joints due to the increase of axial bolt force could become a problem for threads used in heat engines and plant pipelines in running condition. The primary reason of the troubles occurring in bolted joints due to thermal load is the differential elongations between threaded components and the fastened objects. Therefore, the axial bolt force changes, and loosening or an excessively large axial force occurs. This article will first explain the mechanism of metal elongation and shrinkage under thermal load, and then give more detailed information to further understand the complicated behavior of actual bolted joints based on the basic theory.

Metal Elongation and Shrinkage Due to Thermal Load



(Fig. 1)

Metal expands when applying heat, and shrinks when it is cooled. Figure 1 shows the state of elongation of a round bar with length of L under thermal load. The extent of thermal expansion and shrinkage is proportional to temperature change ΔT and the original length L, and is calculated by multiplying them by the coefficient of linear expansion α_{ex} inherent to the material.

$$\delta = \alpha_{ex} \Delta T L \qquad (1)$$

The average coefficient of linear expansion of carbon steel is around 12×10^{-6}. For example, if the temperature of a round bar with 1m length is raised as much as 100°C room temperature, the round bar elongates by approximately 1.2mm. On the contrary, if the bar is immersed into liquefied natural gas, whose temperature is minus 160°C, its temperature drops by 180°C from room temperature and it shrinks by about 2.16mm. In these cases, if the temperature of the round bar is wholly uniform, and its elongation and shrinkage are not restrained, thermal stress does not occur because of the "free expansion" state. On the other hand, when the deformation of the round bar is completely restrained, the magnitude of thermal stress can be calculated using the following equation.

$$\sigma = \alpha_{ex} \Delta T E \qquad (2)$$

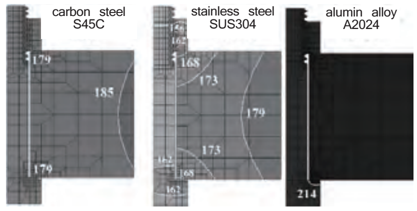
Unlike Equation (1), the equation above does not include the original length L. Instead, Young's modulus E that represents the material stiffness is included. The $\alpha_{ex}\Delta T$ in the equation is called "thermal strain". Equation (2) can be referred to as Hooke's law for thermal stress. If we substitute 100°C for ΔT and 200GPa for Young's modulus E, the thermal stress becomes as high as 240MPa. As the displacement is not completely restrained in actual machines and structures, the amount of thermal stress becomes fairly smaller.

The most widely employed material for threaded components is carbon steel. On the other hand, the anti-rust characteristic makes stainless steel a widely used material as well. However, if stainless steel is used for bolted joints under thermal load, loosening or seizure could become a problem. Although the mechanism of such problems is complicated, the extent of coefficient of linear expansion is one of the main reasons. The coefficient of commonly used austenitic stainless steel is around 17.3×10^{-6}, which is 1.5 times larger than carbon steel. Consequently, it is easy to elongate or shrink under thermal load. For example, when the temperature of the bolted joint, composed of thick carbon steel plates fastened by stainless steel bolts and nuts, is raised, the axial bolt force decreases because its elongation is 1.5 times larger than that of the plates. In the case where the bolts and nuts are made of aluminum alloy, the bolted joint is more likely to loosen because α_{ex} is 2 times larger than carbon steel.

Mechanism of Heat Transfer and Variation of Axial Force

One of the reasons why many troubles occur in threaded fasteners made of stainless steel is that, other than coefficient of linear expansion, thermal conductivity is low. Thermal conductivity is a material constant inherent to each material, expressing the degree of easiness of heat flow. According to Fourier's law, q(W/m^2), the amount of heat flowing within an object, is proportional to temperature gradient dT/dx. The factor of proportion is thermal conductivity λ(W/mK).

$$q = -\lambda \frac{dT}{dx} \qquad (3)$$



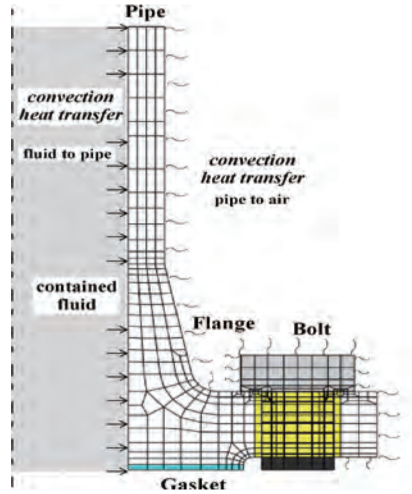
(Fig. 2)

Figure 2 is an analytical example of temperature distributions after a sufficiently long time since uniform heating of hollow cylinder fastened by nuts and bolts is started from the outer surface. The materials of the nuts, bolts and cylinder are identical. Approximate values of thermal conductivity (W/mK) under room temperature are 52 for carbon steel, 16 for stainless steel, and 120 for aluminum alloy. Because of the low conductivity of stainless steel, a large temperature difference is observed between the external part of the cylinder and the bolts/nuts. On the other hand, in the case of aluminum alloy, the temperature distribution is almost uniform.

The mechanism of heat transfer is classified into 3 forms: thermal conduction, heat transfer, and radiation. Heat transfer refers to the heat exchange between solid and liquid, as well as between solid and gas. There is a wide variety of heat transfer phenomena around us such as the heat exchange between the fluid in the pipeline and the pipe surface, or the heat dissipating from cylinder surface of the engine into the atmosphere. The amount of heat transferred in the form of heat transfer, q(W/m^2), is assumed to be proportional to the difference between the surface temperature Ts of the object and the temperature of liquid/gas T∞. The coefficient in the case is referred to as coefficient of heat transfer h(W/m^{2}K).

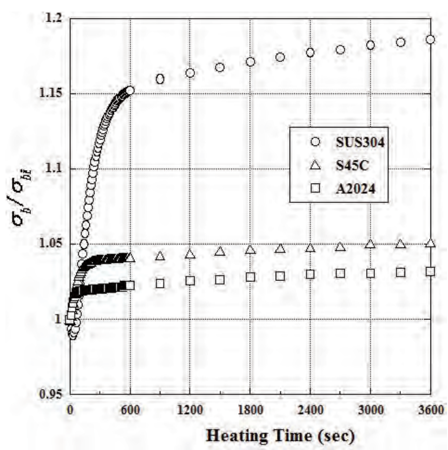
$$q = h\left(T_s - T_\infty\right) \qquad (4)$$

Coefficient of heat transfer *h* changes substantially according to the surface status. **Figure 3** schematically shows the pipeline placed outdoors. When it is subjected to thermal load from the internal fluid, the axial force may change. However, since the temperature distribution reaches a steady state after a certain amount of time, the axial force becomes almost constant. After that, if there is heavy rain, the coefficient of heat transfer may drastically increase and the external surface temperature decreases, thereby possibly resulting in the drastic change in the axial bolt force. It is difficult to correctly estimate the coefficient of heat transfer. For example, when comparing the conditions of the air around the pipeline being still and that of heavy rain, the coefficient of heat transfer in the latter case could be dozens of times larger than the former case. Accordingly, you have to pay special attention to the change of axial bolt force when using bolted joints subjected to thermal load outdoors.

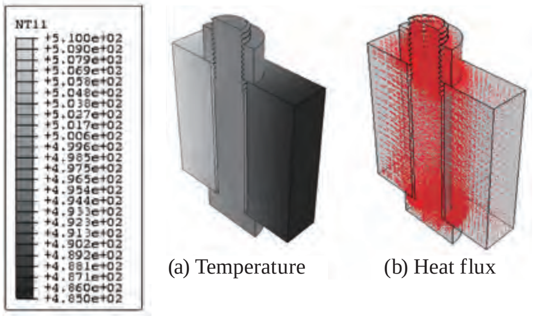


(Figure 3)

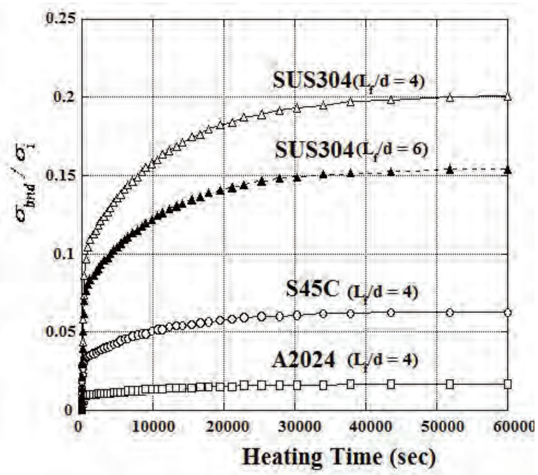
Variation of Axial Force Due to Thermal Load



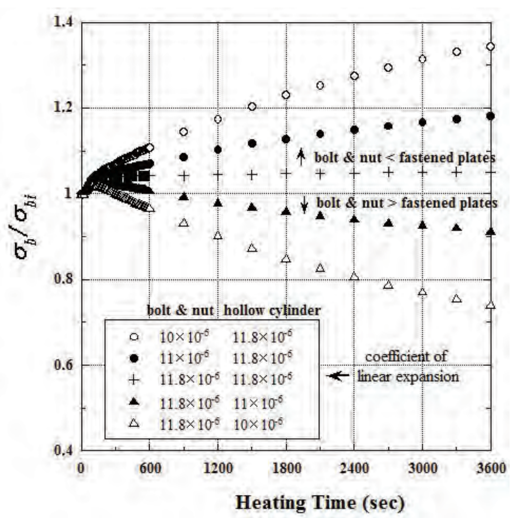
(Figure 4)



(Figure 5)



(Figure 6)



(Figure 7)

Corresponding to **Figure 2**, **Figure 4** shows the variation of axial bolt force from the start of heating to 3,600 seconds. The vertical axis represents the axial stress σ_b at a certain time divided by the initial axial stress σ_{bi}. The axial bolt stress in the case of stainless steel with small thermal conductivity shows about 18% increase after one hour heating. Actual bolted joints seldom receive thermal load in the form as shown in Figure 2. The heat mostly flows in the direction perpendicular to the bolt axis. **Figure 5** shows an analytical example of the distributions of temperature and heat flux. In those cases, in addition to the bolt force variation, bending moment is generated in the bolt body. **Figure 6** shows the variations of bending stress σ_{bnd} with time, which is caused by bending moment. The vertical axis is the divided value of σ_{bnd} by σ_{bi}. The parameter is the ratio of the grip length of the bolted joint L_f to the nominal diameter *d* of bolt. Because the temperature gradient in the direction of heat flow is large for stainless steel with low thermal conductivity, large bending stress occurs. This tendency is remarkably observed in the case of short grip length.

When subjected to thermal load, coefficient of linear expansion is the factor that significantly affects the change of axial bolt force. The phenomenon naturally appears when using the bolt, nut and fastened object made of different materials. Additionally, even if the same materials are used, coefficient of linear expansion inevitably changes to some extent due to the small difference of the ingredients. **Figure 7** shows analytical results, obtained by using the model in **Fig.2**, for varying coefficient of linear expansion α_{ex} of the bolt, nut and fastened object. Assuming the material is carbon steel and α_{ex} of the bolt, nut and fastened object is all set to be 11.8×10^{-6}, the increase rate of the axial bolt stress is around 5% corresponding to **Figure 4**. However, if α_{ex} of the fastened object decreases slightly down to 11×10^{-6} or 10×10^{-6}, the axial stress significantly increases to 19% or 24%. The axial stress conversely decreases when the materials are switched. As shown above, the difference of coefficient of linear expansion among the bolt, nut and fastened object greatly affects the variation of axial bolt force. Additionally, you have to pay attention to the fact that the variation of axial bolt force is almost proportional to temperature change ΔT. The following is the equation estimating the change of the axial bolt force ΔF_b when subjected to thermal load.

$$\Delta F_b = -\frac{(\alpha_b - \alpha_f)\Delta T L_f}{(1/k_b) + (1/k_f)} \qquad (5)$$

α_b and α_f are the coefficients of linear expansion of the bolt, nut, and fastened object. k_b and k_f are the spring constants of the bolt, nut, and fastened object that I explained in my second article. I will show you a simple example of calculation using the above equation. Assuming that the bolt and nut are made of carbon steel, the fastened object is made of stainless steel, and the grip length is 8 times the nominal diameter, when the temperature of the whole bolted joint is raised as much as 200°C, the axial bolt stress shows an increase exceeding 120MPa.

Conclusion

This article explains the basic mechanism of the variation of axial force of the bolted joint under thermal load. In addition to the bolt, nut and fastened object composed of different materials, even the case of the same material combination has a small difference in coefficient of linear expansion, and the axial bolt force changes substantially when encountering the large temperature change. This is an important issue from the design point of view.

Reference:

Toshimichi Fukuoka, "Threaded Fasteners for Engineers and Design – Solid Mechanics and Numerical Analysis –", pp.137-157, Corona Publishing Co., Ltd. (2015)