Journal of Steel Structures & Construction
ISSN: 2472-0437

Research Article Open Access

Develop a Method to Estimate the Tension of Torque-Shear High Strength Bolts

Hwan-Seon Nah*

Smart Energy Lab, Korea Electric Power Corporation Research Institute, Republic of Korea

Abstract

High strength bolts are widely used as a connector of steel member for steel structure. When the torque shear type high strength bolt is fastened, a pin-tail of the bolt is twisted off. The clamping force of the high strength bolt is normally carried out with a visual inspection, so it is uncertain to measure the clamping force quantitatively. To solve this problem, this study developed a method to identify the clamping force of high strength bolt at a digital mode. The new method identify the induced tension is to analyse the accumulated electric energy applied to high strength bolts until the pin-tails are broken by electric torque wrenches. Valuations of bolt clamping forces and accumulated current data were collected through various experiments. The function of accumulated current data using regression analysis was conducted with various values of bolt diameter. The function of accumulated current data by various values of bolt diameter considering torque wrench rpm was conducted by using regression analysis. The measuring deviation between the values measured by a tension meter and those estimated by a trial product of a measuring device developed in this study is only around 4%. Also, as a result of the research, the trial product is developed including algorithms that calculate clamping force according to the different bolt diameter and electric wrench types.

Keywords: Bolt; Tension; Current; Wrench; Torque

Introduction

It is general that the bolted joint connects the main members for a steel structure is designed as a slip critical joint. The high strength bolts have applied to Korean construction sites are torque shear type since 2000. The guidelines for these types of bolts were written in 2003 in Korea. Moreover, the related code ASTM F 2280, as used in the USA, was established in 2006. The torque shear type high strength bolts are designed in a process that pin-tails are twisted off at constant torque. However, it is too difficult to assume that clamping force is properly induced even if proper torque is applied. Even if torque is constant, tension changes when a torque coefficient changes. Therefore, to confirm the introduction of clamping force to a high strength bolt is only valid right after it is manufactured under quality control at the fracture of pin-tail. If the lubricant conditions on surfaces of high strength bolt shank and threads are varied due to temperature, humidity and dust, while it is moved and stored, the proper tension required by the specification cannot be induced. The purpose of this study is to establish the method to determine the induced tension throughout various experiments, algorithms, and related techniques to quantitatively analyse clamping force. Moreover, a trial device embedded algorithms was suggested so that it can be used to assure the quality at sites.

Overseas Technologies

There are no problems related to torque control method as happened to Korea and Japan, since direct tension indicating method rather than torque control method is employed in Europe and North America. Therefore, it is difficult to find reference data relevant to this study. Studies on clamping methods using direct tension and friction joints were carried out as follows. A study reported that the clamping strength of high strength bolts varies depending on the properties and types of lubricant the manufacturer uses in the USA [1-3]. Vand et al. published experimental results comparing torque coefficients between a case where lubricant was applied to the screw threads of high strength bolts and a case where the bolts had no applied lubricant [4]. According to the results of the experiment, the torque coefficient of the lubricated bolts was 0.205 and that of the bolts without lubrication was 0.04. A study by Chakherlou evaluated clamping force in relation to stress and friction strength based on the shape of the edge crack of bolt holes [4]. In a study conducted by Yang et al. the clamping force of bolt joints was compared between ordinary room temperature and high-temperature and the test result was compared with analysis result [5]. In addition, the study analyzed the variation of torque coefficients associated with the difference in bolt length and lubricant applied to high strength bolts [6]. There was a difference of 23% between the test result and the analysis result. As mentioned above, the test results varied depending on test environments and so did the analysis results. In a study conducted by Cleary, clamping force was compared between high strength bolts 1" in diameter having a reinforced washer and those without it. Static test and long-term test were performed on high strength bolts clamped in slotted holes and friction resistance characteristics were estimated for 20 years based on the test result [7]. Axial strength tests of high strength bolted joints with hot dip galvanized surfaces were performed and the results were evaluated [8].

Test Setup

All of the specimens were torque shear type high strength bolts (S10T) which were 20 mm, 22 mm, 24 mm in diameter and 75 mm, 100 mm in length to identify the tension of bolts with analogue tension meter, Skidmore model, MS-102. The surface condition of high strength bolt was provided for two categories; one is plain surfaced, the

***Corresponding author:** Hwan-Seon Nah, Smart Energy Lab, Korea Electric Power Corporation Research Institute, Republic of Korea, Tel: 821031727363; E-mail: hsnah_kepri@kepco.co.kr

Received December 12, 2017; **Accepted** December 20, 2017; **Published** December 27, 2017

Citation: Nah HS (2017) Develop a Method to Estimate the Tension of Torque-Shear High Strength Bolts. J Steel Struct Constr 3: 135. doi: 10.4172/2472-0437.1000135

Citation: Nah HS (2017) Develop a Method to Estimate the Tension of Torque-Shear High Strength Bolts. J Steel Struct Constr 3: 135. doi: 10.4172/2472-0437.1000135

other is zin coated. The applied tools for clamping bolts were electric torque wrenches made in Japan called TONE. The revolution per minutes of tools were composed of 10 rpm for model, HTS 110L. The variables to take diverse tensions from candidate bolts were applied to conditions such as immersion of fresh water, outdoor exposure, surface temperature. The total summary of test is as shown in Table 1.

Torque shear type high strength bolts are clamped using specific electric tools. Electric energy induced until the fracture of the pin-tail due to shearing force directly affects the tension of the high strength bolt. The premise of study was that all the electric energy used to clamp a high strength bolt was the same as the energy induced into the shank of bolt. The electric energy taken from an electric torque wrench was accumulated and analyzed to transform into tension within the useful range. This study is focused on the method to estimate tension by conducting regression analysis on the relation between tension measured by a tension meter and electric energy accumulated until the fracture of pin-tails and storing the result of the analysis in a measuring device.

Figure 1 shows the process of obtaining, transmitting and substituting the clamping force data of high strength bolts from an electric torque wrench. After the initial start-up current, the point where the current is the lowest indicates that clamping starts. The point of the second highest current indicates pin-tail fracture. The lowest current, the lowest power, the highest current and the highest power were determined in a general current curve. A program was configured as shown in Figure 2 to calculate the accumulated currents and accumulated power in order to determine the accumulated amount of energy from the lowest point to the highest point. All of the data measured during the tests was stored in Excel program so that the lowest current, the highest current and finally induced tension can be displayed on the digital screen from the trial product [9-10].

Test and Analysis

Test plan for diameter 20 mm bolts

A hydraulic analogue tension meter (Skidmore MS-102) and an electric torque wrench (TONE, HTS 110L, 10 rpm) were used

Electric Torque Wrench (rpm)	Bolt Type/Diameter	Variables	Q'ty
TONE (10 rpm)	TS Strength Bolt (S10T M20)	Temperature	45
	TS Strength Bolt (S10T M22)	Temperature	40
	TS Strength Bolt (S10T M24)	Temperature immersion	70

Table 1: List of test.

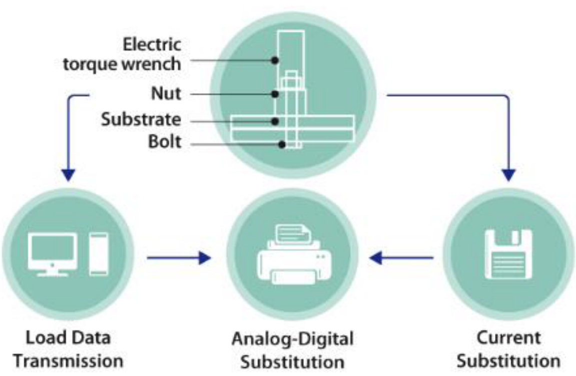

Figure 1: The process of creating data.

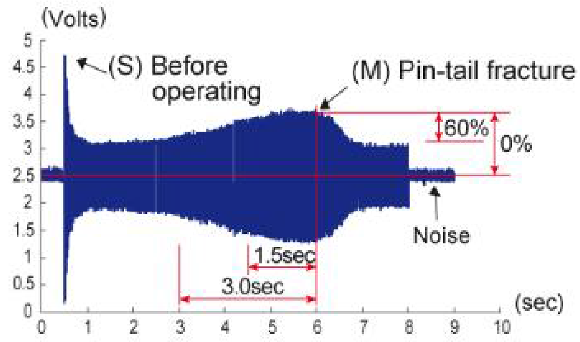

Figure 2: Measuring electric energy from an electric torque wrench.

Bolt Species (Manufacturer)	Identification Number	Variables	Quantity
S10T M20 (H Co.)	R10-HK-20	Surface temp 23℃	15
S10T M20 (H Co.)	R10-HKD-20	Surface temp 23℃	15
S10T M20 (D Co.)	R10-DW-20	Surface temp 23℃	15
Subtotal			45

Table 2: List of Specimens.

to measure tension and gather accumulated electric energy data. Three types of S10T M20 high strength bolts which were 20 mm in diameter and 75 mm to 100 mm in length were used in the test. The test was performed at room temperature without considering various parameters. Specimens in the test are shown in (Table 2).

Analysis result of diameter 20 mm bolt

As in the case of the previous test, measured tension values were compared with the values obtained by using accumulated current data and accumulated power data. The former provided lower error rate. Equation (1) was obtained from the regression analysis of tension as a function of accumulated currents.

$$T=0.0016 \times A.C+148.81 \quad (1)$$

(T: tension (kN), A.C: accumulated currents conversion value)

The average tension obtained from the tension meter was 185.3 kN and the value obtained from eqn. (1) using accumulated currents was 183.9 kN. The error rare was as low as 1.9%. Figure 3 shows the relationship between tension and accumulated currents.

The average tension of 157.4 kN was achieved from the regression analysis of tension in relation to accumulated power. Standard deviation was 2.5. Figure 4 shows the result. It was indicated that the values of tension obtained by using accumulated currents (error rate 1.9%) were much more reliable than those obtained by using accumulated power (error rate 14.9%). In fact, the error rate in the latter was too large for the values to be considered reliable [11-13].

Table 3 summarizes the tension analysis using accumulated currents from an electric torque wrench with 10 rpm.

Test Plan for diameter 22 mm bolts

A hydraulic analogue tension meter (Skidmore MS-102) was used to measure tension. The electric torque wrenches (Model: HTS110L, 10 rpm) manufactured by TONE, a Japanese company, were used to gather accumulated electric energy data. S10T M22 high strength bolts which were 22 mm in diameter and 75 mm in length were used in the

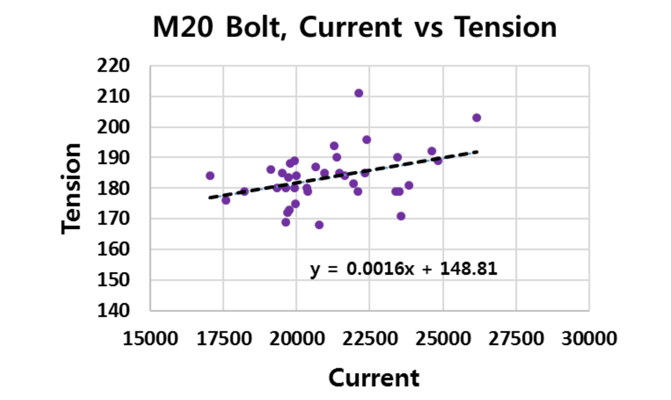

Figure 3: Tension vs. currents (10 rpm).

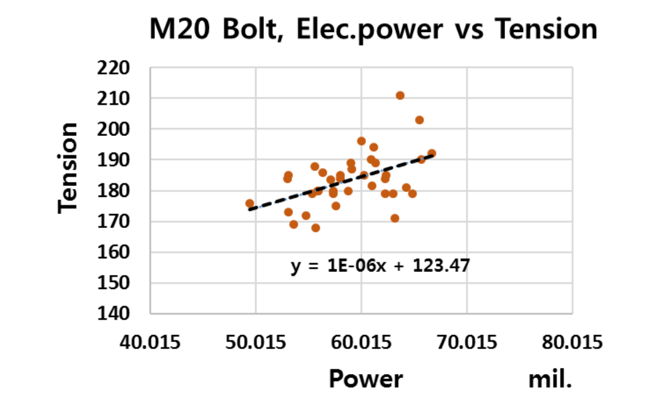

Figure 4: Tension vs. accumulated power.

Identification Number	Measured tension (kN) (A)	Regression analysis		
		Tension Aver. (kN) (B)	Standard Dev.	Error Rate (A-B)
R10-HK-20	185	181	7.3	1.9
R10-HKD-20	183	183	6.4	2.8
R10-DW-20	181	185	11.2	5.2
Average	183	183	8.9	3.4

Table 3: Tension analysis (rpm 10).

test. Three types of torque shear type bolts from two manufacturers were chosen as specimens. Table 4 shows the list of the specimens.

Rotation Speed	Bolt Species/Identification	Variables	Quantity
rpm 10	S10T M22/R10-HK-22	Surface temp. 23℃	20
	S10T M22/R10-HKD-22	Surface temp. 23℃	20
	Subtotal		40

Table 4: List of specimens for 22 mm Dia.

Analysis for diameter 22 mm bolts

The tension of the bolts was measured by an analogue tension meter. The average accumulated currents were retrieved from the Excel program and the trial product. Regression analysis was conducted with the test result. Eqn. (2) for tension as a function of accumulated currents was obtained from the analysis. Figure 5 is the graphical version of the analysis result.

$$T=0.0036 \times A.C+93.151 \tag{2}$$

(T: tension (kN), A.C: accumulated currents (A)).

When an electric torque wrench with 10 rpm was used, the tension of HK-22 measured by a tension meter ranged between 221 kN to 238 kN. The average tension was 229 kN with a standard deviation of 4.8 kN. The tension of HK-22 obtained from the trial product ranged between 219 kN to 245 kN. The average tension was 228 kN with a standard deviation of 8.8 kN. The average error rate of the tension provided by the trial product was 2.4%, which was 0.8% lower than the overall average error rate of 3.2%. When an electric torque wrench with 10 rpm was used, the measured tension of HKD-22 ranged between 192 kN ~272 kN. The average tension was 240 kN with a standard deviation of 18.2 kN. The average tension was higher when compared with conventional high strength bolts. And, a standard deviation width of 7% was significantly large. It is deduced that zinc coated bolt surface and coating thickness exerted influence on the tension. The tension of HKD-22 obtained from the trial product ranged between 219 kN~245 kN. The average tension was 238 kN with a standard deviation of 16 kN. The average error rate of the tension provided by the trial product was 3.7%, which was 0.5% higher than the overall average error rate of 3.2%. The result of the analysis is shown in Table 5. The average error rates ranged between 2.4% and 3.7% and the overall average error rate was 3.2% indicating high level of reliability [14,15].

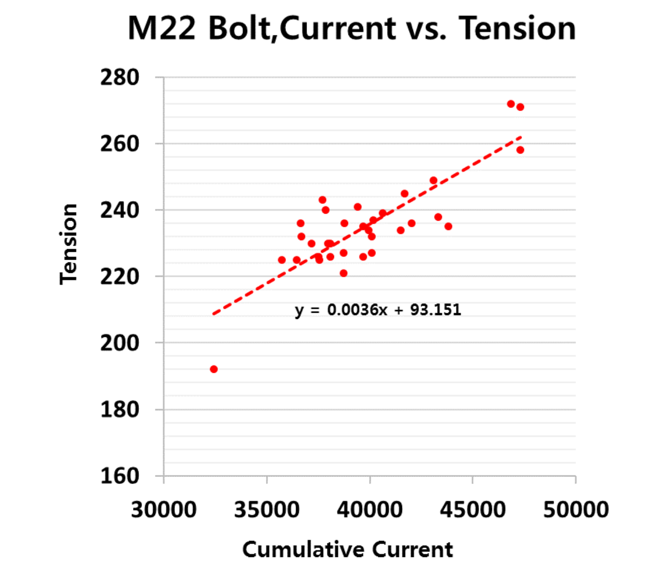

Figure 5: Current vs. Tension (M22 bolts).

Test plan for diameter 24 mm bolts

As shown in the test and analysis of high strength bolts which were 24 mm in diameter, no noticeable changes were identified at using a 10 rpm wrench. A hydraulic analogue tension meter (Skidmore MS-102) was used to measure tension. An electric torque wrench with 10 rpm which is called as HTS110L, manufactured by TONE, a Japanese company, was used to gather accumulated electric energy data.

S10T M24 high strength bolts which were 24 mm in diameter and 80 mm in length were used in the test. Three types of torque shear type bolts from two manufacturers were chosen as specimens. Table 6 shows the list of the bolts tested.

Citation: Nah HS (2017) Develop a Method to Estimate the Tension of Torque-Shear High Strength Bolts. J Steel Struct Constr 3: 135. doi: 10.4172/2472-0437.1000135

Identification Number	Tension Meter (A) (kN)		Trial product (B) (kN)		
	Tension Avr.	Standard Dev.	Tension Avr.	Standard Dev.	(A-B)%
R10-HK-22	229	4.8	228	8.8	2.4
R10-HKD-22	240	18.2	233	16.1	3.7
Subtotal					3.2

Table 5: Result of bolt (M22) tension.

Tool	Identification Number	Environmental Condition	Quantity
Electric Torque Wrench (rpm 10)	R10-HK-24	Surface temp. 23	20
	R10-DWD-24	Surface temp. 23	20
	R10-DW-24	Surface temp. 23	20
	R10-HK-W30-24	Immersion for 30 min. Exposure for 24 hours	10
Sub total			70

Table 6: List of specimens for 24 mm Dia.

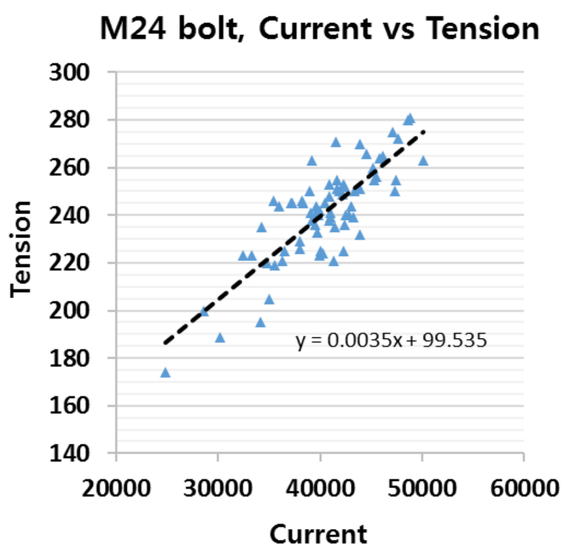

Figure 6: Estimation by accumulated currents.

Analysis for diameter 24 mm bolts

The tension of the bolts which were 24 mm in diameter was analysed as follows. Regression analysis was conducted for tension values measured by an analogue meter as a function of accumulated currents from an electric torque wrench. Figure 6 shows the result of the analysis. Eqn. (3) was obtained from the analysis. The coefficient of determination (R^2) at this time was 0.67.

$$T=0.0035 \times A.C+99.535 \tag{3}$$

(T: tension (kN), A.C: accumulated currents (A))

The average tension of R10-HK-24 provided by the equation was 250 kN with a standard deviation of 9.3. The average error rate calculated from the comparison with measured values was only 3.0%. While the average tension of R10-HK-W30-24 bolts which were exposed to air for 24 hours after being immersed in water for 30 minutes was also 250 kN, the standard deviation was 11.3 and the average error rate was 4.6%. In addition, the values of average tension varied depending on manufacturers of the bolts. The values provided by the trial product ranged between 226 kN~250 kN and those measured by a tension meter ranged between 222 kN~ 249 kN. Table 7 showed the summarized result.

The averages of tension values measured by a tension meter were within the range between 244 kN~249 kN, except for 222 kN observed in R10-DW-24. The average tension values provided by the trial product presented a similar pattern. The standard deviations 11.0~17.0 in projected values indicated a tendency to be closer to the mean than the standard deviations 12.7~21.7 in measured values.

Configuration of a Trial Product

The trial product consists of sensing part which detects alternating current and voltage provided by an electric wrench through a current transformer; sampling part which limits the number of sensed current and voltage data to 60 per second to reduce processing time; programming part which decides the effective range (minimum value maximum value) for measured current and voltage; programming part which decides the number of effective data to be received per second for each rpm (9~20); and part which provides information that the selected data (current or voltage) results in lower mathematic error rates. Figure 7 shows the configuration. Inside the device are: part which provides regression analysis algorithms for the relation between tension and accumulated currents based on various test results; programming part which executes additional regression analysis and modifies algorithms as required by the features of an electric wrench; part which computes accumulated currents, accumulated voltages and accumulated power immediately; and part which determines tension using accumulated

Identification Number	Tension Meter (A) (kN)		Trial product (B) (kN)		(A-B) Error Aver.(%)
	Tension Aver.	Standard Dev.	Tension Aver.	Standard Dev.	
R10-HK-24	248	12.7	248	11	3.1
R10-DWD-24	249	15.1	239	13	4.3
R10-DW-24	222	18.6	229	15.9	4.3
R10-HK-W30-24	244	21.7	250	17	4.6
Subtotal	231	20.1	236	16.4	4.4

Table 7: Result of bolt (M24) tension by accumulated currents.

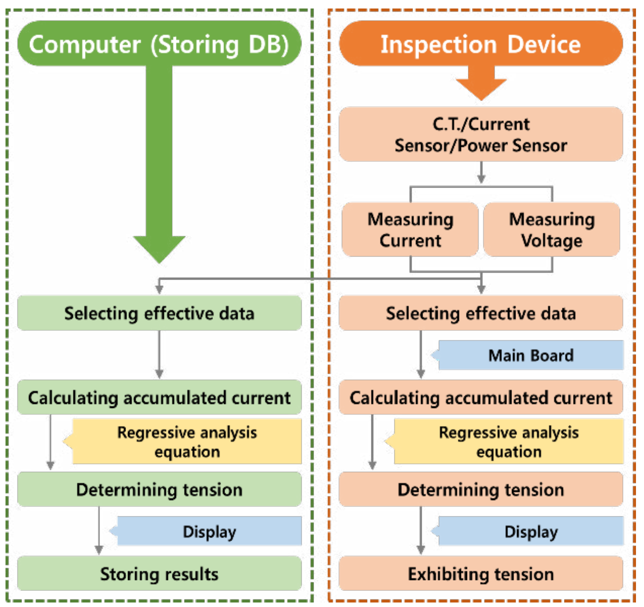

Figure 7: Concept map of a trial product of a tension inspection device.

Figure 8: Trial product.

power as shown. Outside the device are: outlet where an tension meter and an electric wrench are connected to electricity supply; outlet where an electric wrench is connected to electricity supply; display panel for current and voltage in progress; display panel for final tension, minimum current, maximum current and accumulated current; memory card where data is stored; reset part which deletes stored or preceding data; USB part which upgrades programs; power switch; and hardware which calculates, analyzes, determines and stores measured currents and voltages and calculated power at a separate computer. The trial product is shown on Figure 8.

Conclusion

The study was focused on observation of the measured and calculated values of tension in relation to the diameters of bolts and input data in order to develop a trial product of an inspection device to measure clamping force induced to torque shear type high strength bolts. The clamping tests were performed to check the induced tension dependent to variables on types and diameters of high strength bolts which were 20 mm, 22 mm and 24 mm in diameter and 75 mm and 100 mm in length. Electric torque wrench with 10 rpm, which was widely known, was used and effective electric energy was analyzed until the pintails were twisted off. Linear regression analysis was conducted to identify the relation among tension and accumulated currents and accumulated power. New equations were provided from regression analysis to calculate tension based on accumulated currents.

In case of bolt diameter 20 mm, the clamping force can be estimated as follows:

$T=0.0016 \times A.C+148.81.$

In case of bolt diameter 22 mm, the clamping force can be estimated as follows:

$T=0.0036 \times A.C+93.151.$

In case of bolt diameter 24 mm, the clamping force can be estimated as follows:

$T=0.0035 \times A.C+99.535.$

As shown above, average error rates of tension values calculated by using accumulated currents were approximately 4% regardless of bolt diameter. The inspection method and device suggested and developed in this study estimated the clamping force of high strength bolts for friction joints. They are expected to be used for the safety assurance of bolted joints in steel structures, given extended data. The algorithms drawn from this study and the inspection device can be useful to estimate the current tension of high strength bolts clamped to existing structures by determining the initial clamping force of the bolts.

References

1. Kulak GL, Fisher JW, Struik JHA (2002) Guide to Design Criteria for Bolted and Riveted Joints, (2nd edn.), AISC Inc Chicago IL.
2. Bickford JH (2008) An Introduction to the Design and Behaviour of Bolted Joints, (4th edn.), CRC Press, New York, NJ.
3. Tambori Akbar R (1999) Handbook of structural steel connection design and detail Design, McGraw-Hill, USA.
4. Vand HE, Oskouei RH, Chakherlou TN (2008) Experimental Method for Measuring Clamping Load in Bolted Connections and Effect of Bolt Threads Lubrication on its Value. World Academy of Science, Engineering and Technology 10: 457- 460.
5. Yang Kuo-Chen, Hsu Re-Jia, Chen Yan-Jun (2011) Shear Strength of High strength Bolts at Elevated Temperature. Construction and Building Materials 25: 365.
6. Abdalla K, Dimitrios N, Charalambos K, Baniotopoulos C (2011) Tightening and Loosening Torque of M253 Bolts: Experimental and Analytical Investigation. International Journal of Engineering and Information Sciences 6: 69-83.
7. Heistermann C, Veljkovic M, Simoes R, Rebelo C, Da Silva S et al. (2013) Design of slip resistant lap joint with long open slotted holes. J Construc Steel Research, 82, 223-233.
8. Minami K, Tokutomi Y, Shimizu O, Kawamura K, Morii S (2013) Bolt Tightening Tests of High Strength Bolted Joint with Metal Sprayed Contact Surfaces. Civil Institute of Japan 69: 133-138.
9. Architectural Institute of Japan (2003) Guidebook on Design and Fabrication of High Strength Bolted Connections, AIJ.
10. ASTM F 2280-06 (2006) Twist Off Type Tension Control Structural Bolt/Nut/ Washer Assemblies, Steel, Heat Treated, 150ksi Minimum Tensile Strength, ASTM International, Philadelphia, PA
11. Nah HS, Lee HJ, Kim KS, Kim JH, Kim WB (2009a) Method for Estimating the Clamping Force of High Strength Bolts Subjected to Temperature Variation. Inter J Steel Struc 9: 123-130.
12. Nah HS, Lee HJ, Kim KS, Kim JH, Kim WB (2009b) Evaluation of Slip Coefficient of Slip Critical Joints with High Strength Bolts". Struc Eng Mech 32: 477-488.
13. Nah HS, Lee HJ, Kim KS, Kim JH, Kim WB (2010) Evaluating Relaxation of High strength Bolts by Parameters on Slip Faying Surfaces of Bolted Connections. Inter J Steel Struc 10: 295-303.
14. Nah HS, Lee HJ (2015) Estimation on Clamping Force of High Strength Bolts Considering Temperature Variable of Both Site Conditions and Indoor Environments. J. Korean Soc Adv Comp. Struc 6: 32-40.
15. RCSC Committee (2000) Specification for Structural Joints Using ASTM A325 or A490 Bolts, AISC.