Journal of Engineering and Development, Vol. 9, No. 3, September (2005) ISSN 1813-7822

Effect of Previous Fire on Load-Slip Relationship at a Modified Push-Out Test (Experimental Study)

Asst. Lect. Mukhallad A. Al-Sa'ady
Environmental Engineering Department, College of Engineering
Al-Mustansiriya University, Baghdad, Iraq

Abstract

In this paper, the effect of previous heating on load-slip relationship in modified push-out test is studied. Specimens of concrete slab with connectors (connector embedded in the concrete slab) were put in an oven of high heating for at least one hour after reaching a specified temperature (300~700) ^{o}C. Due to these high temperatures, the compressive strength of concrete was reduced and cracks were seen on the surface of concrete. The slip was increased and the stiffness of the connector was decreased significantly. It is concluded that the effect of previous heating on the connector stiffness is greater than its effect on the compressive strength of concrete due to presence of cracks in concrete after heating to high temperatures.

الخلاصـــة

*في هذا البحث، دُرسَ تأثير الحريق المسبق على علاقة القوة-الأنزلاق في فحص ال (**push-out**) المعدل. نماذج من الكونكريت مع الرابط (الرابط دفن في بلاطة الكونكريت) وضعت في الفرن لمدة لا تقل عن ساعة بعد الوصول الى درجة الحرارة المطلوبة (٣٠٠~٧٠٠) درجة مؤية. نتيجة هذه الحرارة العالية، حَصلَ نقصان في مقاومة الانظغاط مع ظهور تشققات على سطح الكونكريت، الزحف أزداد وصلادة الرابط نقصت بشكل ملحوظ.*

أستنتج ان التاثير المُسبقْ للحريق على صلادة الرابط أكبر من تأثيره على مقاومة الانضغاط للكونكريت نتيجة وجود التشققات في الكونكريت عند ارتفاع درجات الحرارة العالية.

1. Introduction

Information on the shear connector stiffness is essential for using in equation of partial interaction theory of composite steel-concrete beams (including steel-concrete-steel sandwich beams, multi-layer beam system… etc). Though the behavior of shear connectors has bean under investigation for many years, most studies have focused on the shear connector strength. Of the publications available regarding the behavior of the shear connectors, only a few provide descriptions of the shear connector load-slip curve to enable the determination of the shear connector stiffness [1].

The shear connector load-slip curve is generally nonlinear, and there is no unified definition of the shear connector stiffness. Johnson and May [2] (1975) defined the shear connector stiffness as the secant stiffness at half the shear connector ultimate load.
Yam and Chapman [3] (1968) presented a study for the inelastic behavior of simply supported composite beams, based on Newmark's model. A nonlinear behavior is assumed for the shear connectors, which is presented in the following exponential form.

$$\mathbf{Q = a \cdot \left(1 - e^{-b\cdot\gamma}\right)} \quad \text{……………………………………………………………} \mathbf{(1)}$$

in which (a) and (b) are constants of idealized load/slip function of a shear connector, (γ) is the slip at interface, (Q) is the shear load on the connector. By choosing two points from the experimental curve so that the slip in the second point is twice its value at the first point, the constants can be defined as:

$$\mathbf{a = \frac{Q_1^2}{2\cdot Q_1 - Q_2}} \quad \text{…………………………………………………………...} \mathbf{(2)}$$

$$\mathbf{b = \frac{1}{\gamma_1}\log_e\left(\frac{Q_1}{Q_2 - Q_1}\right)} \quad \text{……………………………………………………...…} \mathbf{(3)}$$

in which, subscripts (1 and 2) represent the points on the experimental load –slip curve for the provided shear connector. **Figure (1)** shows a typical load-slip relationship (exponential formula).

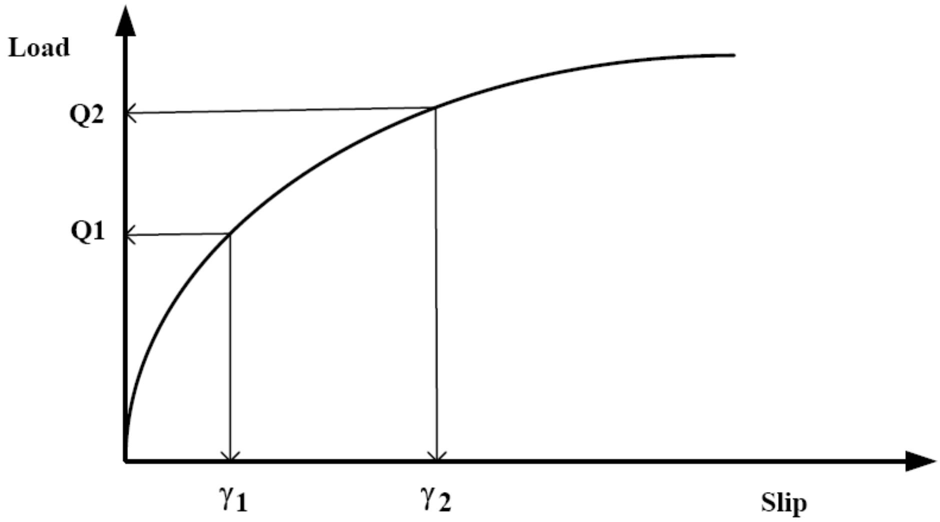


Figure (1) Typical Load-Slip Relationship from the Standard Push-Out Test

Al–Amery and Roberts [4] (1990) proposed a theoretical model for the analysis of composite beams with partial interaction. In this model, the load-slip curve for the connectors is a modified form of the exponential function suggested by Yam and Chapman, as follows:

$$\mathbf{Q = Q_u \cdot \{1 - \exp(-\alpha . u_{ab})\}} \quad \text{.. (4)}$$

in which, (Q_u) is the ultimate shear strength of a connector and (α) is a constant, which can be determined from test results. For example:

$$\boldsymbol{\alpha = \frac{1}{\bar{u}_{ab}} \cdot \ln\left(\frac{Q_u}{Q_u - \bar{Q}}\right)} \quad \text{.. (5)}$$

in which, ($\bar{u}_{ab}$) is the slip corresponding to a load ($\bar{Q}$).

Although there are several mathematical expressions describing the shear connector load-slip curves, the studies indicated that it was rather difficult to find a general regression formula for the shear connector stiffness because of the extent of scatter in this value when plotted against other parameters [5, 6, 7, 8, and 9].

2. Resistance of Concrete to Fire

In general, concrete has good properties with respect to fire resistance, since the period of time under fire after which concrete can continue to perform satisfactorily is relatively high, but fire introduces high temperature gradients, and as a result the hot surface layers tend to separate and spall away from the cooler interior of the body. The formation of cracks is encouraged at joints, in poorly compacted parts of the concrete, or in the planes of reinforcing bars. Once the reinforcement has become exposed, it conducts heat and accelerates the action of heat [10].

In this study, and in order to specify the change in the compressive strength of concrete after heating at specified temperatures (300, 400, 500,600 and 700) ^{o}C, three concrete cylinders of dimensions (10*20) cm, and specimens of concrete slab used in the manufacture of push-out test, were put in an oven of high heating (as shown in **Fig.(2)**). After heating the specimens to high temperatures for at least one hour, the heating was stopped; the temperature was reduced gradually and the specimens were tested under normal conditions. **Figure (3)** shows variation of concrete compressive strength after heating to high temperatures.

Previous research [5] shows that the effect of increase in temperature on the strength of concrete is small and somewhat irregular below (250) ^{o}C but above about (300 ^{o}C a definite loss of strength takes place.

Figure (2) Pictures; (A): An Oven of High Heating (Up to 1200 ^{o}C); (B): A Specimen to be Heated

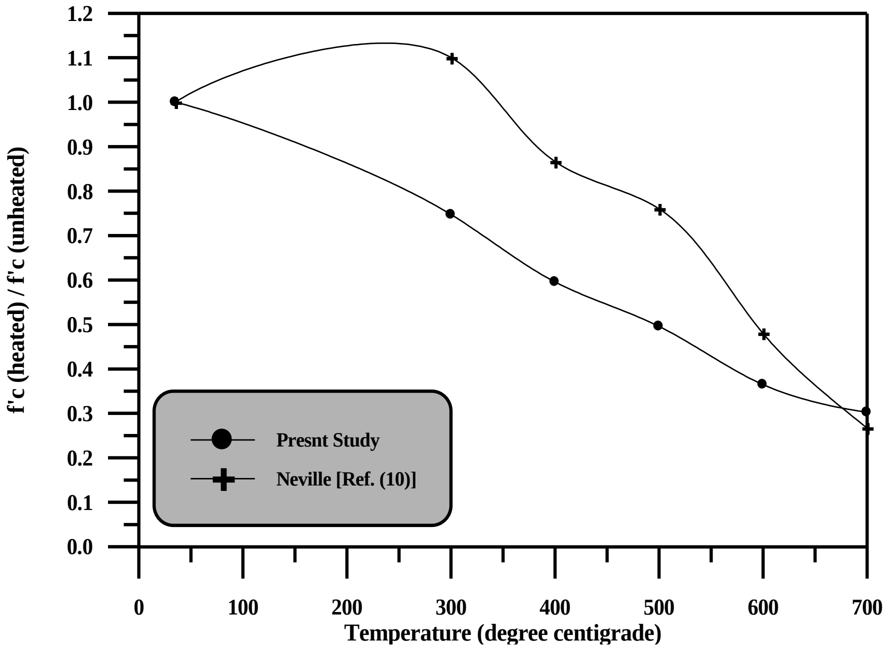


Figure (3) Compressive Strength of Concrete after Heating to High Temperatures [10]

3. Material Properties

The concrete used to manufacture the test beams is designed to have a cylinder compressive strength between (30~40) MPa at age of (28) days. The cement which is used in the mixture of concrete is Ordinary Portland Cement (Spline) made in Lebanon and the sand is (Al-Akhaidher) with fineness modulus (2.8), while the gravel is a crushed with maximum size equal to (16) mm. The proportion of mixture (by weight) is (1) cement: (1.7) sand: (2) gravel with water cement ratio equal to (0.45). At least three Cylinders (10*20) cm were made from each batch using in the manufacturing of the push-out test. These were cured under the same conditions (the cylinder left in water up to (28) day) as the concrete slab and both the cylinders and the slabs were heated in an oven, at the same time, after approximately (32) days (in air) beyond the end of curing. The average cylinder compressive strength is (45) MPa. A threaded stud is used as a connector with specifications and details as given in **Table (1)**.

Table (1) Specification and Test Results of Stud-Average Values

Stud Type	Measured Diameter (mm)		Tu (kN) From Tensile Test	Qu (kN) From Push-Out Test	Qu/Tu From Test	Max. Measured Slip (mm)
	Inner*	Outer				
Threaded stud along the whole length	6.2	7.2	18.33	12	0.655	1.89

* Inner diameter is used in all calculations and relations.

4. Details of Test Specimens and Instrumentation

The suggested push-out test consists of two steel columns of rectangular hollow section (100*100*6) mm and one concrete slab of dimensions (450*300*100) mm (as shown in **Fig.(4)**). The connector which is used in this test is a stud threaded along the whole length. This stud is embedded in the concrete slab and projected through the steel columns (details of connection as well as other dimensions and details of push-out test are shown in **Fig.(5)**).

The load is applied on the concrete slab by steel plate used as a cupping to distribute the applied force on the concrete part. Under each steel column a piece of wood is used also to distribute the transmitted force from the concrete to the steel columns through the connector and to prevent relative movement at the base of the columns. The total applied load is measured by a loading machine and the relative movement (slip) between the concrete and the steel is measured at each connector as well as at the base of concrete by using dial gages, so that five dial gage are used and the average of these readings are taken to construct the load-slip relationship. It is worthy to mention that the test was stopped when one of the connectors, at any location, was broken (fractured).

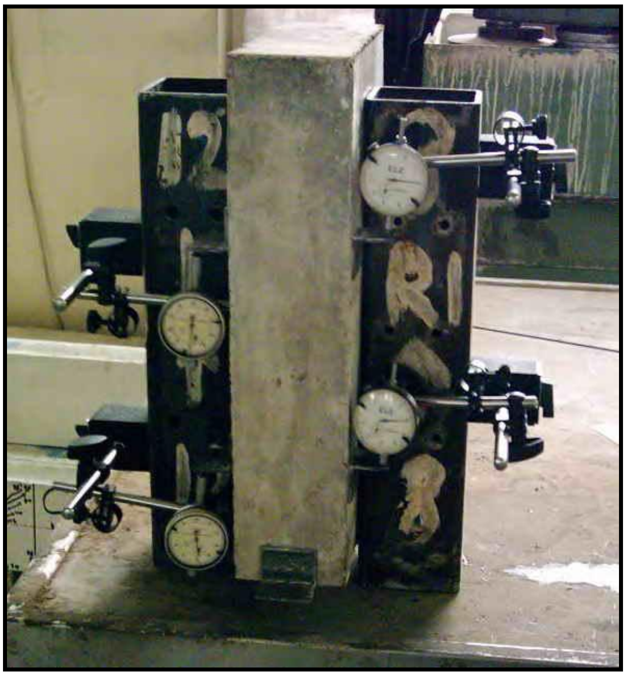


Figure (4) Modified Push-Out Test

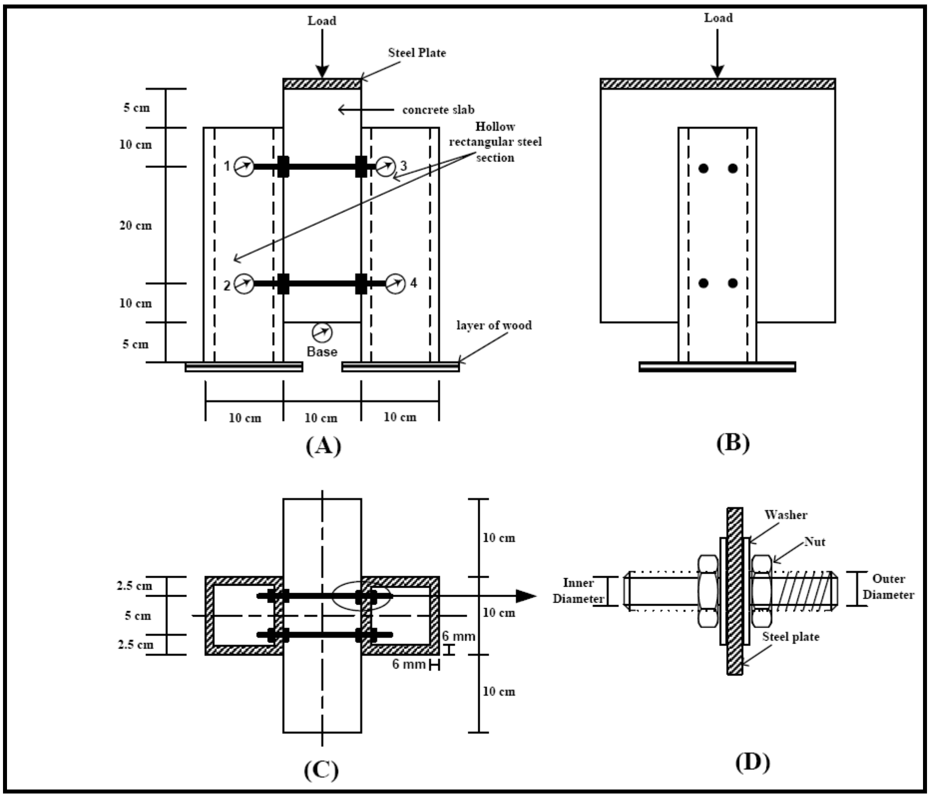


Figure (5) Dimensions and Details of Modified Push-Out Test; (A): Front View; (B): Side View; (C): Top View; (D): Details of Connection (Magnified Picture)

5. Results and Discussions

Eight push-out tests (of the same properties) were carried out in order to study the load-slip relationship after heating to high temperatures. Three of which were tested without previous heating (these were used to construct an average load-slip curve (reference curve)). The others were heated to varying temperatures (300,400,500,600 and 700) ^{o}C. One push out test was made for each temperature. The connector was embedded in a concrete slab of push-out test and it was also subjected to these temperatures. Load-slip relationship is constructed for each test depending on the average value of five dial-gage measurements (dial gages were used to measure the slip at each connector and at the base of concrete slab).

The connector force was not affect after these temperatures as shown in **Fig.(6)**, but the amount of slip increased significantly with elevated heating temperatures. This increased slip decreased the stiffness of the connector as shown in **Fig.(7)**. **Figure (8)** shows that the effect of heating on the connector stiffness is greater than its effect on the concrete compressive strength since the slope of the fitting curve (linear equation) between these two parameters is greater than (1) (the angle with horizontal line is greater than (45^{o})).

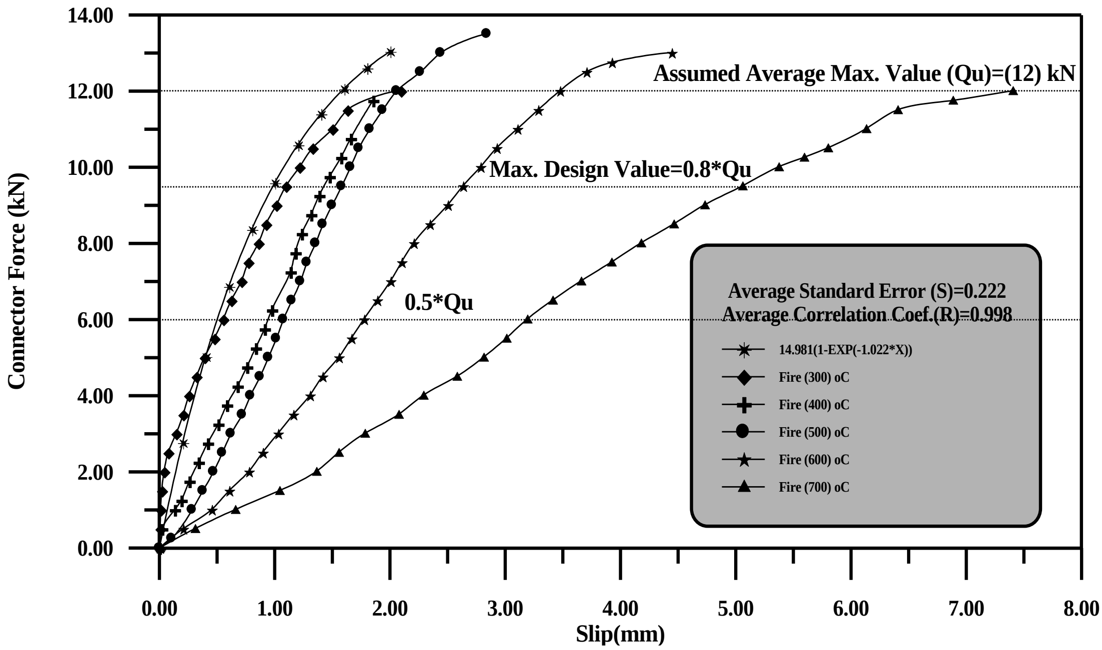


Figure (6) Load-Slip Relationship of Connector after Heating to Different Temperatures

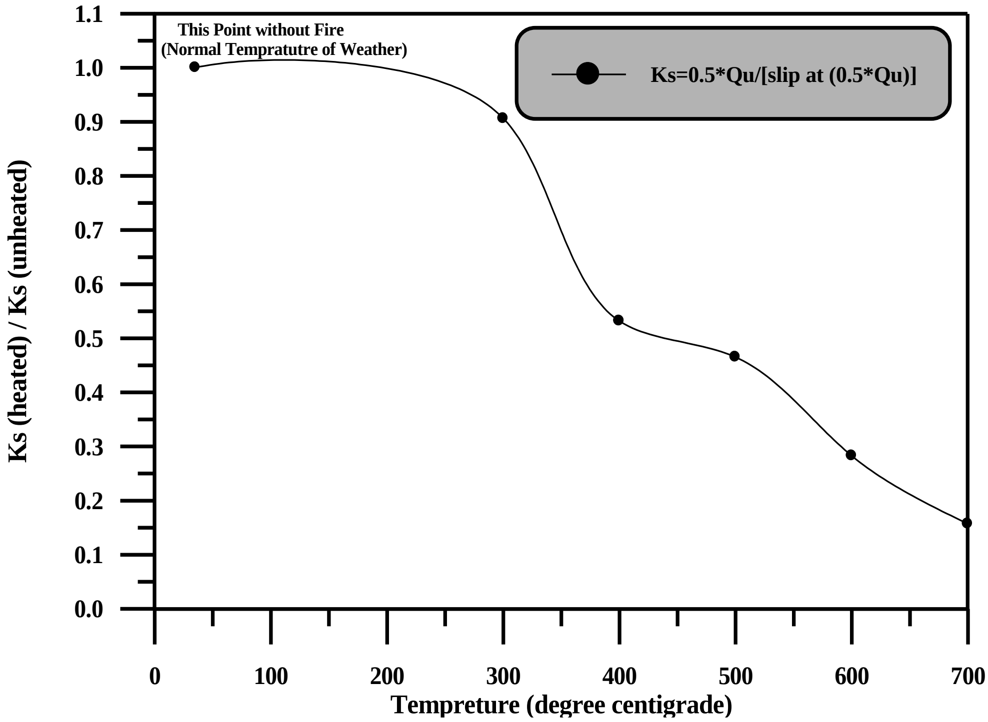


Figure (7) Connector Stiffness Ratio after Heating to Different Temperatures

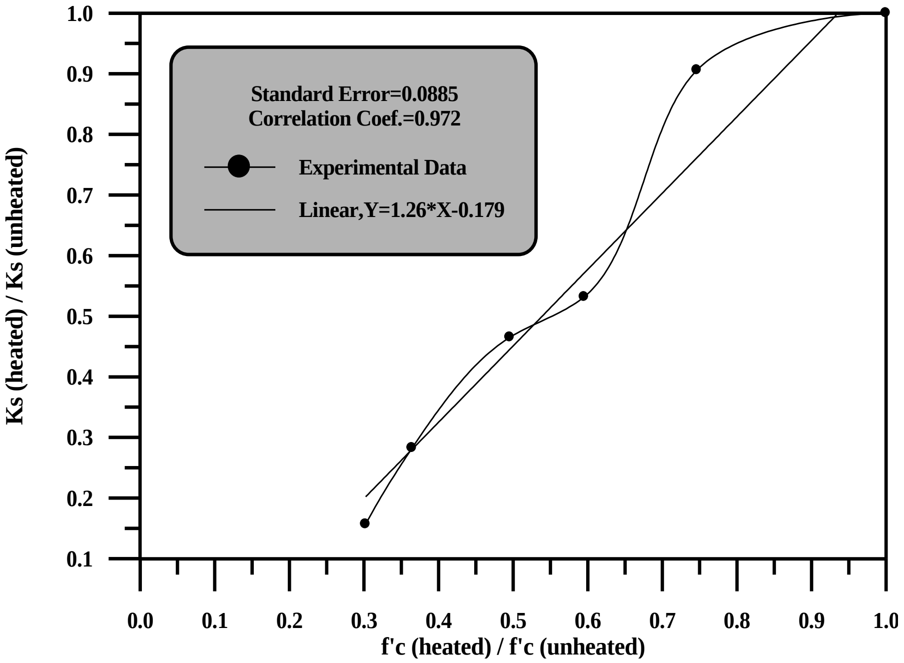
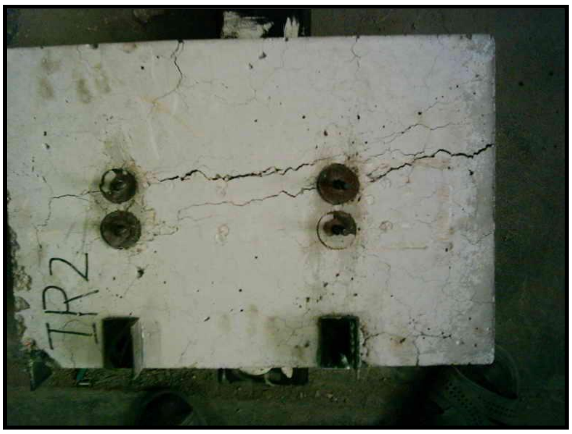


Figure (8) Variation of Connector Stiffness Ratio with the Concrete Compressive Strength Ratio

Figures (9) and **(10)** show pictures of concrete slab of push-out after test, splitting of concrete begins to occur at temperature 600 ^{o}C from the bottom connector to the top connector in the same side.



(A) **(B)**

Figure (9) Pictures of Push-Out Concrete Slab after Test; (A): Without Heating; (B): Previously Heated to (700) ^{o}C

(A) (B)

Figure (10) Pictures of Connector Region after Test; (A): Previously Heated to (600) °C; (B): Previously Heated to (700) °C

6. Conclusions

From the modified push-out tests, it can be seen the following points:

1. The previous heating to different temperatures does not affect the ultimate force of the connector which is used in this study (since the diameter is small, and the failure is predominated by the shear cutoff of the connector instead of the splitting of concrete slab even when used in unreinforced concrete).

2. The compressive strength is reduced significantly after heating to temperatures greater than (300) ^{o}C in comparison with unheated concrete.

3. Cracks are seen on the surface of concrete at temperature (500) ^{o}C.

4. Due to heating effect at varying temperatures (300~700), the decrease in the ratio [FK = Ks (heating) / Ks (without heating)] of the connector stiffness is greater than the decrease in the ratio [Ff'c = f'c (heating)/f'c (without heating)] of concrete compressive strength (i.e. FK = 1.25 * Ff'c).

7. References

1. Wang, Y. C., ***"Deflection of Steel-Concrete Composite Beams with Partial Shear Interaction"***, Journal of Structural Engineering, Vol.129, No.10, 1998, pp. 1159-1165.

2. Johnson, R. P., and May, I. M., ***"Partial-Interaction Design of Composite Beams"***, Journal of the Structural Engineer, Vol.53, No.8, pp. 305-311, 1975.

3. Yam, L. C. P., and Chapman, J. C., ***"The Inelastic Behavior of Simply Supported Composite Beams of Steel and Concrete"***, Proc. Instn. Civ. Engrs. , Vol.41, 1968, pp. 651-683.

4. Al-Amery, R. I. M., and Roberts, T. M., ***"Nonlinear Finite Difference Analysis of Composite Beams with Partial Interaction"***, Journal of Computers and Structures, Vol.35, No.1, 1990, pp. 81-87.

5. Khaleel, M. A., ***"Behavior and Strength of Stud Connectors Subjected to Combined Shear and Tension Loading in Composite Structures"*** M. Sc. Thesis, Al-Mustansiriya University, 1998, 145 pp.

6. Oduyemi, T. O. S., and Wright, H. D., ***"An Experimental Investigation into the Behavior of Double-Skin Sandwich Beams"***, Journal of Construct. Steel Res., Vol.14, 1989, pp. 197-220.

7. Roberts, T. M., Edwards, D. N., and Narayanan, R., ***"Testing and Analysis of Steel-Concrete-Steel Sandwich Beams"***, Journal of Construct. Steel Res., Vol.38, No.3, 1996, pp. 257-279.

8. Al-Amery, R. I., and Al-Sa'ady, M. A., ***"Nonlinear Behavior of Shear Connectors in Layered Beam System with Partial Interaction"***, Fifth Scientific Conference of Baghdad University, College of Engineering, 2003.

9. BS 5400, Part 5, ***"Steel, Concrete and Composite Bridges"***, British Standard Institution, London, 1979.

10. Neville, A. M., ***"Properties of Concrete"***, Second Edition, 1977, 687 pp.

Notations

a, b	= Constants.
$f'c$	= Characteristic cylinder compressive strength of concrete.
Q	= Connector force.
Qu	= Ultimate load of the connector.
Tu	= Ultimate tensile stress.
Uab	= Relative movement between layers.
γ	= Slip interface.
α	= Constants.