**Steel and Composite Structures**, *Vol. 30, No. 2 (2019) 141-147*
DOI: https://doi.org/10.12989/scs.2019.30.2.141


# Behavior of steel-concrete composite beam using angle shear connectors at fire condition

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(*Received June 26, 2018, Revised October 7, 2018, Accepted January 11, 2019*)

**Abstract.** Fire is one of the environmental parameters affecting the structure causing element internal forces to change, as well as reducing the strength of the materials. One of the common types of floors in tall steel structures is the steel concrete composite slab. Shear connectors are used in steel and concrete composite beam in various shapes also has played significant role in a burning fire event of building with a steel concrete composite beam. The current study has reviewed the effects of temperature raising on the angle connector behavior through the use of push out tests and monotonic static force. The results have shown (1) the ductility of the samples is acceptable based on EC4 standard; (2) temperature raising has reduced the stiffness; (3) the shear ductility increment; and (4) the shear capacity reduction. Also, the amount of angle shear connector resistance has been decreased from 18.5% to 41% at ambient temperature up to 850°C.

**Keywords:** composite steel-concrete beams; elevated temperatures; push-out tests; angle shear connectors; load-slip graphs

## 1. Introduction

Steel-concrete composite constructions are applied in buildings and bridges since early 1920s, so steel-concrete composite beam systems has recently become popular in buildings and bridges (Bazzaz *et al*. 2011, 2012). The combinations of concrete and steel have produced a shear connection between them by using mechanical connectors. Recently many researches have been conducted on behavior of C-shaped shear connectors like channel and angles (Shariati *et al*. 2010, 2011a, b, c, 2012a, b, c, d, e, 2013, 2014a, b, 2015, 2016, 2017, Tahmasebinia *et al*. 2012, Shariati 2013a, b, 2014, Wei and Xiao 2013, Toghroli *et al*. 2014, Fanaie *et al*. 2015, Khalilian 2015, Khorramian *et al*. 2015, Khorramian *et al*. 2017, Shahabi *et al*. 2016a, b, Tahmasbi *et al*. 2016, Khorramian *et al*. 2017, Mansouri *et al*. 2017, Wei *et al*. 2017, 2018, Hosseinpour *et al*. 2018, Nasrollahi *et al*. 2018, Paknahad *et al*. 2018, Chahnasir *et al*. 2018, Sedghi *et al*. 2018).

The recent knowledge in this field has been limited to the behavior and shear connector capacity obtained from practical experiments including push-out tests and rarely composite beam test. The bending strength of the steel-concrete composite beams has highly been influenced by the strength and ductility of the shear connectors (Bazzaz *et al*. 2012, 2015, Andalib *et al*. 2018).

Considering fire as a highly destructive occurring, on temperature rising, the mechanical properties of the materials have been decreased highlighting the importance of structural fire designing. The related studies on fire safety design has begun around 90 years ago (Ingberg 1928). Behavioral diversion, specifically, in the application of steel and concrete in steel-concrete composite beams has produced a behavior complexity under fire due to the non-uniform heat distribution along the height of the slab thickness of different materials. Meanwhile, temperature raising has reduced the efficiency of the shear connector signifying the awareness of the shear connector behavior at high temperatures. In a direct exposing of steel and concrete to fire, the shear connectors have been indirectly influenced by temperature raising (Fig. 1).

Though, some studies on shear connector have been widely carried out in ambient temperature, the number of laboratory and numerical studies on the shear connectors behavior at high temperatures are limit (Yasuda *et al*. 2008, Mirza and Uy 2009, Rodrigues and Laím 2011, 2014, Chen *et al*. 2012, 2015, Lu *et al*. 2012, Shahabi *et al*. 2016a). Techniques for testing have approximately followed a global stable scale in the late 60 years based on ISO834-1 1999 and BS476- PARTS 20-23 in England. ASTM standard for fire resistance tests, C19 (now E119) has been published in 1918. The standard curves of BS and ASTM are shown (Fig. 2).

Standard fire curves as the simplest method for displaying a fire by the temperature-time relationship separate from boundary conditions and ventilation have described the variations of heat flames in a standard furnace. Standard or Nominal fire model has been developed for fire resistance furnace tests of building materials. Lennon *et al*. (1999) has declared “Standard fires do not represent real natural fire” proposed as disadvantage

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http://www.techno-press.org/?journal=scs&subpage=6 ISSN: 1229-9367 (Print), 1598-6233 (Online)

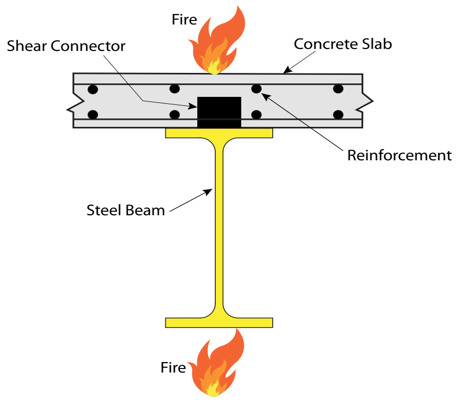


Fig. 1 The effect of fire directly and indirectly on the steel-concrete composite beam (Mirza and Uy 2009)

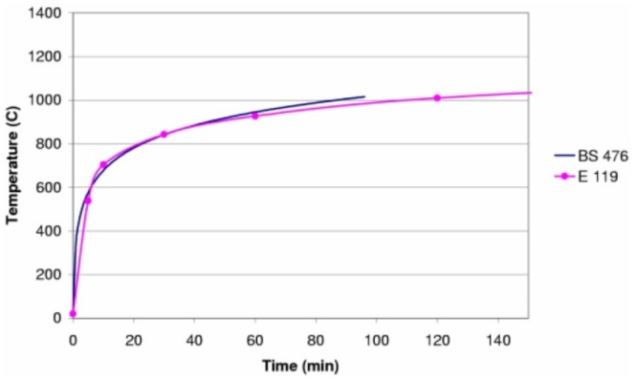


Fig. 2 Standard temperature- time curves (Shahabi *et al*. 2016b)

due to the variations among them like duration, intensity of the fire and the heating rate causing different structural behaviors in fire, say a short duration high temperature fire has produced spalling of concrete, whereas, a long duration low temperature has reduced concrete strength. Standard fires has not always shown the worst fire situation, so the structure members have been designed on the basis of standard fires destroyed in real fire. For instance, buildings have generally been furnished from the equipment maintained from hydrocarbon fuels like plastics, artificial leather, and polymers producing a severe fire than the conventional standard fire. Despite all the limitations of standard fire model, the simplest and most practical way to model the fire conditions are based on the standard fire resistance tests.

According to literature, several experiments have been carried out on a shear stud and Perfobond under static and cyclic loads at ambient temperatures (Ollgaard *et al*. 1971, Oguejiofor and Hosain 1994, Gelfi *et al*. 2002, Valente and Cruz 2004, Lam and El-Lobody 2005, Lee *et al*. 2005, Cândido-Martins *et al*. 2010, Moradi *et al*. 2016, Safa *et al*. 2016, Shahabi *et al*. 2016b, Toghroli *et al*. 2016, Khorami *et al*. 2017). Few other experimental tests have been conducted on the behavior of angle and the channel shear connectors under the monotonic and cyclic loads at ambient temperatures (Pashan 2006, Maleki and Bagheri 2008, Shariati *et al*. 2012d, Soty and Shima 2013, Khorramian *et al*. 2015, Balasubramanian and Rajaram 2016, Khorami *et al*. 2017). Due to the shear stud and Perfobond application confinement like time consuming and cost, the use of C-shaped angles and channel shear connector have highly been recommended. Meanwhile, the angles and channels have a large shear capacity easily welded to the steel profile in construction. An angle shear connector has been used in either c-shaped or L-shaped manner. Across the use of L-shaped angle, there is a possibility of concrete uplifting. Also, C-shaped angle has less steel in the absence of the lower flange compared to the channel due to its economical usage (Shariati *et al*. 2012e).

In the angle shear connector application, while no laboratory tests is carried out under the effects of temperature raising, few has been conducted in shear studs and channel shear connectors. Two researchers (Zhao and Kruppa 1995) have implemented a series of tests on push-out specimens to obtain shear capacity and load-slip graphs of shear stud and channel shear connector based on ISO 834-1, therefore, slabs has been considered as solid concrete and steel decks in the form of trapezoidal. While the load (all different loads) is constant, all samples are heated until the full destruction occurring. The specimen failures with the concrete solid slabs and the steel deck are always occurred due to the shear failure of the shear stud in the beam flange level (Zhao and Kruppa 1995). Choi *et al*. (2009) has examined the resistive properties of the shear studs at high temperatures in push- out test. According to ISO standard test, samples are heated between 30 to 60 minutes, so the temperature has changed between 10 mm and 50 mm when the reference points is 200°C for 30 minutes and 300°C for 60 minutes. The shear stud failure has been occurred due to the shear created at the welding contact surface with the shear stud edge; accordingly, to evaluate the residual resistivity of the shear studs, the relationship has been evaluated by Choi *et al*. (2009). Quevedo and Silva (2013) have performed another thermal analysis on push-out samples under the influence of heat raising. While the first group has consisted of samples at room temperature, the second one has included few samples under the influence of temperature raising. On the other hand, the load is not to estimate the length raising due to temperature increasing. In the third group, shear studs with variable diameters and identical height in concrete slabs with steel deck under different load levels and fire have been investigated. Performing the experiments, the heat is directly applied to two concrete slabs edge and steel profile (Quevedo and Silva 2013). Yasuda *et al*. (2008) has conducted high-temperature push-out experiments including two shear studs arranged on a H-beam section to model the behavior of two slabs types, one solid slab and one metal deck. Meanwhile, Yasuda *et al*. (2008) has investigated the effects of concrete strength, shear force magnitude and heat conditions resulting that the main point of design is the heat at the end of the shear stud. Lu *et al*. (2012) has presented the application of shear connector on a steel deck at different temperatures to estimate the shear behavior of shot-nailed and screwed connections at ambient and

Table 1 Chemical composition of ordinary Portland cement type II according to ASTM C150 (% by mass)

| $P_2O_5$ | $SO_3$ | $K_2O$ | MgO | CaO | $Fe_2O_3$ | $Al_2O_3$ | $SiO_2$ | $TiO_2$ | MnO | $CO_2$ | LOI |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.068 | 4.25 | 0.281 | 2.08 | 64.09 | 2.064 | 4.27 | 18.47 | 0.103 | 0.045 | 4.20 | 1.53 |

elevated temperatures led to the failure modes consisting of thinner plate rupture and rupture of shear connectors (Lu *et al*. 2012). Chen *et al*. (2012) has performed several experiments on 7 push-out samples at different temperatures, also the test heat is provided by facing two electrical plates on both sides of the push-out samples. The proposed relation has been compared to other proposed equations by researchers. The dominant slabs failure with a parallel deck corrugation to the steel beam has been considered as the shear connector failure, however, the slabs failure at low temperature with a perpendicular deck corrugation to the steel beam has comprised (1) concrete cracking failure and (2) the shear failure of the shear stud at high temperatures.

## 2. Experimental program

### *2.1 Material and mix properties*

Push-out specimens has consisted of a steel I-beam with two slabs attached to each flange of the beam. One angle is welded to each beam flange and two layers of steel bars with four 10 mm diameter steel bar hoops are applied in two perpendicular directions for all slabs according to Maleki and Bagheri (2008); Maleki and Mahoutian (2009). Six types of angles with height of 100, 75 and 65 mm and length of 30 and 50 mm are used (Table 3 and Fig. 3), besides the use of maximum nominal crushed granite aggregate size about 10 mm and silica sand with a maximum nominal size of 4.75 mm. The compressive strength of concrete at 28 days of age is 63 MPa. To maintain workability (Table 2), a super plasticizer SP (Rheobuild 1100) has been added to the fresh mix at 1% of cement weight followed the use of Ordinary Portland Cement (OPC) type II in concrete processing (Table 1).

Table 2 Concrete mix proportion

| SP | w/c | Water ($kg/m^3$) | Coarse Agg. ($kg/m^3$) | Fine Agg. ($kg/m^3$) | Cement ($kg/m^3$) |
|---|---|---|---|---|---|
| 1 | 0.5 | 180 | 940 | 870 | 360 |

Table 3 Angle dimensions and geometries used in push-out tests

| Specimen | *h* (mm) | *w* (mm) | *t* (mm) |
|---|---|---|---|
| A6530 | 65 | 30 | 5 |
| A6550 | 65 | 50 | 5 |
| A7530 | 75 | 30 | 6 |
| A7550 | 75 | 50 | 6 |
| A10030 | 100 | 30 | 7 |
| A10050 | 100 | 50 | 7 |

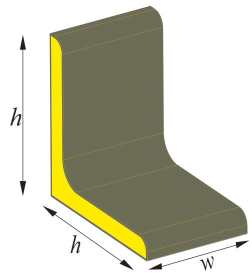

Fig. 3 Angle geometries

Considering the confined steel bars with a nominal diameter of 10 mm and yield stress of 300 MPa (all samples), IPE270 of 400 mm in length and yield stress 240 MPa has mainly used for testing.

As previously mentioned, testing process has consisted of 6 push-out c-shaped angle samples with equal legs (Table 3) selecting the angle size to observe the effects of the height and length increment within the tests. Samples' named are abbreviated, say letter A is abbreviated to the word Angle, on the other hand, the first two digits are applied to show the height of angle leg, while the second two digits are for the angle length. For example, A6550 is an angle sample with height of 65 mm and length of 50 mm.

### *2.2 Push-out specimens*

Test samples are included an IPE270 profile, say an angle as a connector has been welded to each profile flange by fillet weld, also two concrete blocks with dimensions 150×250×300 are placed on both sides of the IPE270 profile (Fig. 4). In order to prevent the cracking of concrete, a transverse closed rectangular reinforcement with a diameter of 10 mm per concrete block have been provided, meanwhile, the reinforcement applied in rectangular closed stirrups in two upper and lower rows has been kept in two rows of vertical reinforcement.

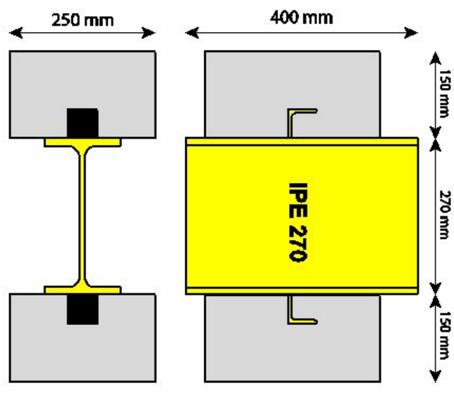

Fig. 4 Push-out size specimens

### *2.3 Push-out test*

Samples are tested by a universal machine with a capacity of 1000 KN. A uniform load is applied at the end of concrete blocks while the steel profile is placed on a fixed base. To apply uniform load on concrete blocks, a steel frame is used. The model has been loaded at a displacement rate of 0.04 mm/s with a displacement control method.

### *2.4 Increased temperature*

Ceramic elements are used in temperature raising. Push-out tests have been conducted at four situations including ambient, 550°C, 700°C and 850°C. To prevent temperature dropping during the test, the glass wool cover has been wrapped around the samples to keep the heat. Testing process has included (1) taking the temperature to the required level; (2) using a steady pressure through the hydraulic jack. Force increment has been kept on until the sample is ruptured.

## 3. Test results

### *3.1 Failure modes*

Basically, the failure modes observed in push out tests has included two reasons: (1) a category consists of angle shear connector fracture, and (2) concrete crushing-splitting. In this study, all damages have been occurred because of the angle shear connectors' failure similar to the case in using high-strength concrete. Strength reduction in shear connector plus the temperature increasing have provoked the failure's occurring in overturning mode instead of usual shear failure followed by load- slip curve's sharp dropping at the end (Fig. 5). At high temperatures, few samples have indicated more invisible ductility (Fig. 5). The reinforcement of push-out samples is another reason for the angles failure (Table 4), therefore, fractures have been occurred near the connection point between angle and steel beam flange due to angle web yield. The maximum force and slip rates of samples are shown in Table 4.

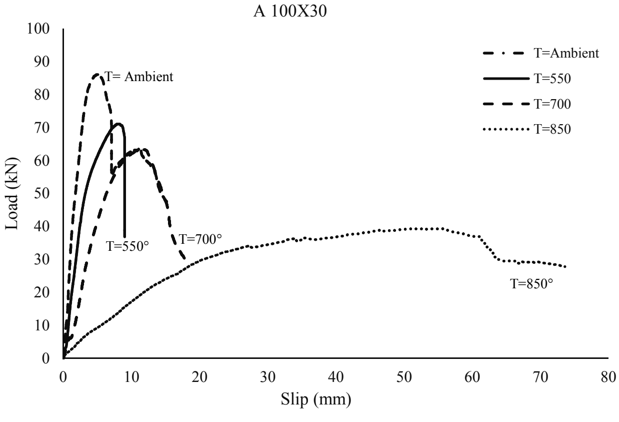


Fig. 5 Specimens A100×30 at ambient, 550°, 700°, 850°

### *3.2 Load- slip relation at ambient and elevated temperatures*

The load- slip diagrams for angles at several temperatures are shown (Figs. 5-6). Loads and displacement values have been recorded automatically by universal testing machine. These figures show load- slip graphs for

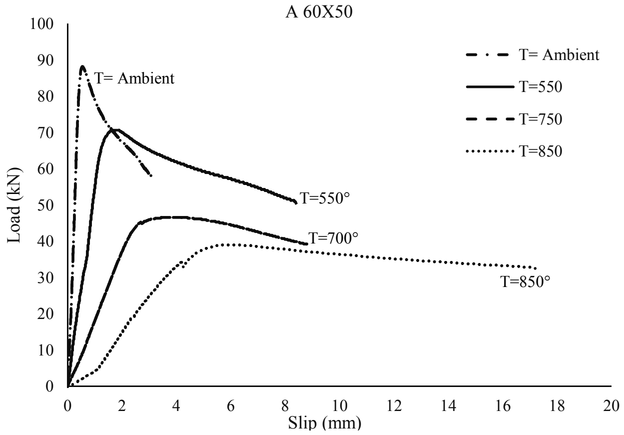


Fig. 6 Specimens A65×50 at ambient, 550°, 700°, 850°

Table 4 Specimens' failure load versus slip at elevated temperature

| Specimen | Temperature | Failure load (kN) | Slip (mm) |
|---|---|---|---|
| A6530 | Ambient | 70.4 | 0.5 |
| | 550 | 56.9 | 6.5 |
| | 700 | 49.2 | 10.0 |
| | 850 | 21.3 | 19.0 |
| A6550 | Ambient | 88.1 | 1.5 |
| | 550 | 70.8 | 5.5 |
| | 700 | 45.7 | 7.0 |
| | 850 | 39.1 | 13.5 |
| A7530 | Ambient | 99.1 | 1.5 |
| | 550 | 81.4 | 4.5 |
| | 700 | 63.8 | 7.5 |
| | 850 | 47.8 | 10.0 |
| A7550 | Ambient | 103.3 | 1.5 |
| | 550 | 85.7 | 3.0 |
| | 700 | 74.4 | 9.5 |
| | 850 | 44.4 | 13.0 |
| A10030 | Ambient | 86.7 | 3.0 |
| | 550 | 70.7 | 5.0 |
| | 700 | 63.4 | 11.0 |
| | 850 | 51 | 40.0 |
| A10050 | Ambient | 126.7 | 2.0 |
| | 550 | 105.7 | 6.0 |
| | 700 | 95.2 | 9.5 |
| | 850 | 58.3 | 17.0 |

A100×30 and A60×50 specimens at four temperatures of ambient, 550°C, 700°C and 850°C

Considering the specimens A100×30, the maximum shear capacity at 550°C is 18.5% lower than the ambient temperature, at 700°C is 26% and at 850°C is more than 41%. Therefore, based on EC4, all specimens have shown a ductile behavior, however, in few specimens, high temperature has decreased the strength about 50%.

### *3.3 Effects of angle geometry*

A fixed height assumption for an angle with length growing (30 to 50 mm), the average of shear capacity has increased by 27.5% at ambient temperature. If the angle length is constant, the shear strength average raising in the height growing is about 16.67%. Therefore, the angle length raising on the ultimate strength is more effective than the height raising (Tahmasbi *et al*. 2016).

## 4. Conclusions

In this paper, various sizes of the angle connector under different temperatures have been tested in push-out experiments under monotonic static force. The experiments have been carried out under the influence of temperature increasing according to ISO-834 standard. The effects of some factors such as temperature raising from room temperature to 850°C and the raising of angle height and angle length under the monotonic loading till the sample failure's occurring have been studied. In all samples, load-slip curves have been plotted at different temperatures. In the following, the failure modes and the reduced resistance have been investigated showing that the ductility of the samples is acceptable according to EC4 standard. The results have also shown that temperature raising has reduced the stiffness but increased the shear ductility and reduced the shear capacity. The amount of angle shear connector resistance has been decreased (18.5% to 41%) at ambient temperature up to 850°C. Meanwhile, the angles strength decline ratio is more than the concrete strength's decline ratio at high temperatures. Angle shear connectors might fail in an overturning mode instead of the usual shear failure because of the heat raising in the bottom layers of concrete material, so the angle shear connectors' temperature are approximately 100°C-150°C higher than the surrounding concrete. To sum up, the results of the experiments have shown that at high temperatures, the ultimate strength is averagely 50% of the initial strength.

## References


Andalib, Z., Kafi, M.A., Bazzaz, M. and Momenzadeh, S. (2018), "Numerical evaluation of ductility and energy absorption of steel rings constructed from plates", *Eng. Struct.*, **169**, 94-106.

Balasubramanian, R. and Rajaram, B. (2016), "Study on behaviour of angle shear connector in steel- concrete composite structures", *Int. J. Steel Struct.*, **16**(3), 807-811.

Bazzaz, M., Kheyroddin, A., Kafi, M.A. and Andalib, Z. (2011), "Evaluating the performance of steel ring in special bracing frame", *Proceedings of the 6th Seismology and Earthquake Engineering International Conference*, Ministry of Science, Research and Technology.

Bazzaz, M., Kheyroddin, A., Kafi, M.A. and Andalib, Z. (2012), "Evaluation of the seismic performance of off-centre bracing system with ductile element in steel frames", *Steel Compos. Struct., Int. J.*, **12**(5), 445-464.

Bazzaz, M., Andalib, Z., Kheyroddin, A. and Kafi, M.A. (2015), "Numerical comparison of the seismic performance of steel rings in off-centre bracing system and diagonal bracing system", *Steel Compos. Struct., Int. J.*, **19**(4), 917-937.

Cândido-Martins, J.P.S., Costa-Neves, L.F. and Vellasco, P.D.S. (2010), "Experimental evaluation of the structural response of Perfobond shear connectors", *Eng. Struct.*, **32**(8), 1976-1985.

Chen, L., Li, G. and Jiang, S. (2012), "Experimental studies on the behavior of headed studs shear connectors at elevated temperatures", *Proceedings of the 7th International Conference on Steel & Aluminum Structures*, Kuching, Sarawak, Malaysia.

Chen, L.Z., Ranzi, G., Jiang, S.C., Tahmasebinia, F. and Li, G.Q. (2015), "Behaviour and design of shear connectors in composite slabs at elevated temperatures", *Constructional Steel Research*, **115**, 387-397.

Choi, S.K., Han, S.H., Nadjai, A., Ali, F., Kim, S.B. and Choi, J. (2009), "Performance of shear studs in fire", Applications of Structural Fire Engineering Czech Technical University, Prague, Czech Republic. pp. 490-495.

Fanaie, N., Esfahani, F.G. and Soroushnia, S. (2015), "Analytical study of composite beams with different arrangements of channel shear connectors", *Steel Compos. Struct., Int. J.*, **19**(2), 485-501.

Gelfi, P., Giuriani, E. and Marini, A. (2002), "Stud shear connection design for composite concrete slab and wood beams", *Struct. Eng.*, **128**, 1544-1550.

Hosseinpour, E., Baharom, S., Badaruzzaman, W.H.W., Shariati, M. and Jalali, A. (2018), "Direct shear behavior of concrete filled hollow steel tube shear connector for slim-floor steel beams", *Steel Compos. Struct., Int. J.*, **26**(4), 485-499.

Ingberg, S. (1928), "Tests of the severity of building fires", *NFPA Quarterly*, **22**(1), 43-61.

Khalilian, M. (2015), "Angle shear connectors capacity", *Modares Civil Eng. J.*, **15**(3), 51-62.

Khorami, M., Khorami, M., Motahar, H., Alvansazyazdi, M., Shariati, M., Jalali, A. and Tahir, M.M. (2017), "Evaluation of the seismic performance of special moment frames using incremental nonlinear dynamic analysis", *Struct. Eng. Mech., Int. J.*, **63**(2), 259-268

Khorramian, K., Maleki, S., Shariati, M. and Sulong, N.R. (2015), "Behavior of tilted angle shear connectors", *PLoS one*, **10**(12), 1-11.

Khorramian, K., Maleki, S., Shariati, M., Jalali, A. and Tahir, M.M. (2017), "Numerical analysis of tilted angle shear connectors in steel-concrete composite systems", *Steel Compos. Struct., Int. J.*, **23**(1), 67-85.

Lam, D. and El-Lobody, E. (2005), "Behavior of headed stud shear connectors in composite beam", *Struct. Eng.*, **131**(1), 96-107.

Lee, P.G., Shim, C.S. and Chang, S.P. (2005), "Static and fatigue behavior of large stud shear connectors for steel-concrete composite bridges", *Constr. Steel Res.*, **61**(9), 1270-1285.

Lennon, T., Moore, D.B. and Bailey, C. (1999), "The behaviour of full-scale steel- framed buildings subjected to compartment fires", *Struct. Engr.*, **77**(8), 15-21.

Lu, W., Ma, Z., Mäkeläinen, P. and Outinen, J. (2012), "Behaviour of shear connectors in cold-formed steel sheeting at ambient and elevated temperatures", *Thin-Wall. Struct.*, **61**, 229-238.

Maleki, S. and Bagheri, S. (2008), "Behavior of channel shear connectors, Part I: Experimental study", *Constr. Steel Res.*, **64**(2), 1333-1340.

Maleki, S. and Mahoutian, M. (2009), "Experimental and analytical study on channel shear connectors in fiber-reinforced concrete", *Constr. Steel Res.*, **65**(8-9), 1787-1793.

Mansouri, I., Shariati, M., Safa, M., Ibrahim, Z., Tahir, M.M. and Petković, D. (2017), "Analysis of influential factors for predicting the shear strength of a V-shaped angle shear connector in composite beams using an adaptive neuro-fuzzy technique", *J. Intel. Manuf.*, 1-11.

Mirza, O. and Uy, B. (2009), "Behaviour of headed stud shear connectors for composite steel-concrete beams at elevated temperatures", *Constr. Steel Res.*, **65**(3), 662-674.

Moradi, M., Valipour, H., Foster, S.J. and Bradford, M.A. (2016), "Deconstructable steel–fibre reinforced concrete deck slabs with a transverse confining system", *Mater. Des.*, **89**, 1007-1019.

Nasrollahi, S., Maleki, S., Shariati, M., Marto, A. and Khorami, M. (2018), "Investigation of pipe shear connectors using push out test", *Steel Compos. Struct., Int. J.*, **27**(5), 537-543.

Oguejiofor, E. and Hosain, M. (1994), "A parametric study of perfobond rib shear connectors", *Can. J. Civil Eng.*, **21**(4), 614-625.

Ollgaard, J.G., Slutter, R.G. and Fisher, J.W. (1971), "Shear strength of stud connectors in lightweight and normal-weight concrete", *AISC Eng. J.*, **8**(2), 55-64.

Paknahad, M., Bazzaz, M. and Khorami, M. (2018), "Shear capacity equation for channel shear connectors in steel-concrete composite beams", *Steel Compos. Struct., Int. J.*, **28**(4), 483-494.

Pashan, A. (2006), "Behaviour of channel shear connectors: push-out tests", Doctoral Dissertation; Saskatchewan, Canada.

Quevedo, R.L. and Silva, V.P. (2013), "Thermal analysis of push-out tests at elevated temperatures", *Fire Safety*, **55**, 1-14.

Rodrigues, J.P.C. and Laím, L. (2011), "Behaviour of Perfobond shear connectors at high temperatures", *Eng. Struct.*, **33**(10), 2744-2753.

Rodrigues, J.P.C. and Laím, L. (2014), "Experimental investigation on the structural response of T, T- block and T-Perfobond shear connectors at elevated temperatures", *Eng. Struct.*, **75**, 299-314.

Sadeghi Chahnasir, E., Zandi, Y., Shariati, M., Dehghani, E., Toghroli, A., Mohamed, E.T., Shariati, A., Safa, M., Wakil, K. and Khorami, M. (2018), "Application of support vector machine with firefly algorithm for investigation of the factors affecting the shear strength of angle shear connectors", *Smart Struct. Syst., Int. J.*, **22**(4), 413-424.

Safa, M., Shariati, M., Ibrahim, Z., Toghroli, A., Baharom, S.B., Nor, N.M. and Petkovic, D. (2016), "Potential of adaptive neuro fuzzy inference system for evaluating the factors affecting steel-concrete composite beam's shear strength", *Steel Compos. Struct., Int. J.*, **21**(3), 679-688.

Sedghi, Y., Zandi, Y., Toghroli, A., Safa, M., Mohamad, E.T., Khorami, M. and Wakil, K. (2018), "Application of ANFIS technique on performance of C and L shaped angle shear connectors", *Smart Struct. Syst., Int. J.*, **22**(3), 335-340.

Shahabi, S.E.M., Sulong, N.H., Shariati, M., Mohammadhassani, M. and Shah, S.N.R. (2016a), "Numerical analysis of channel connectors under fire and a comparison of performance with different types of shear connectors subjected to fire", *Steel Compos. Struct., Int. J.*, **20**(3), 651-669.

Shahabi, S., Sulong, N., Shariati, M. and Shah, S. (2016b), "Performance of shear connectors at elevated temperatures-A review", *Steel Compos. Struct., Int. J.*, **20**(1), 185-203.

Shariati, M. (2013a), "Behaviour of C-shaped shear connectors in steel concrete composite beams", Ph.D. Thesis; Faculty of engineering University of Malaya, Kuala Lumpur, Malaysia.

Shariati, M. (2013b), "Behaviour of C-shaped Shear Connectors in Steel Concrete Composite Beams", Jabatan Kejuruteraan Awam, Fakulti Kejuruteraan, Universiti Malaya.

Shariati, A. (2014), "Behaviour of C-shaped Angle Shear Connectors in High Strength Concrete", M.Sc., Jabatan Kejuruteraan Awam, Fakulti Kejuruteraan, Universiti Malaya.

Shariati, M., Ramli Sulong, N.H., Maleki, S. and Arabnejad Kh, M.M. (2010), "Experimental and analytical study on channel shear connectors in light weight aggregate concrete", *Proceedings of the 4th International Conference on Steel & Composite Structures*, Sydney, Australia, July.

Shariati, M., Ramli Sulong, N.H., Sinaei, H., Khanouki, A., Mehdi, M. and Shafigh, P. (2011a), "Behavior of channel shear connectors in normal and light weight aggregate concrete (experimental and analytical study)", *Adv. Mater. Res.*, **168**, 2303-2307.

Shariati, M., Ramli Sulong, N.H., Arabnejad Khanouki, M.M. and Shariati, A. (2011b), "Experimental and numerical investigations of channel shear connectors in high strength concrete", *Proceedings of the 2011 World Congress on Advances in Structural Engineering and Mechanics* (*ASEM'11+*), Seoul, South Korea, August.

Shariati, M., Sulong, N.R., Kh, M.A. and Mahoutian, M. (2011c), "Shear resistance of channel shear connectors in plain, reinforced and lightweight concrete", *Sci. Res. Essays*, **6**(4), 977-983.

Shariati, M., Sulong, N.R., Suhatril, M., Shariati, A., Khanouki, M.A. and Sinaei, H. (2012a), "Behaviour of C-shaped angle shear connectors under monotonic and fully reversed cyclic loading: An experimental study", *Mater. Des.*, **41**, 67-73.

Shariati, M., Sulong, N.R. and Khanouki, M.A. (2012b), "Experimental assessment of channel shear connectors under monotonic and fully reversed cyclic loading in high strength concrete", *Mater. Des.*, **34**, 325-331.

Shariati, M., Ramli Sulong, N., Suhatril, M., Shariati, A., Arabnejad Khanouki, M. and Sinaei, H. (2012c), "Fatigue energy dissipation and failure analysis of channel shear connector embedded in the lightweight aggregate concrete in composite bridge girders", *Proceedings of the 5th International Conference on Engineering Failure Analysis*, Hilton Hotel, The Hague, The Netherlands, July.

Shariati, A., Sulong, N.R., Suhatril, M. and Shariati, M. (2012d), "Investigation of channel shear connectors for composite concrete and steel T-beam", *Int. J. Phys. Sci.*, **7**(11), 1828-1831.

Shariati, A., Ramli Sulong, N.H. and Shariati, M. (2012e), "Various types of shear connectors in composite structures: A review", *Int. J. Phys. Sci.*, **7**(22), 2876-2890.

Shariati, M., Sulong, N.R., Suhatril, M., Shariati, A., Khanouki, M.A. and Sinaei, H. (2013), "Comparison of behaviour between channel and angle shear connectors under monotonic and fully reversed cyclic loading", *Constr. Build. Mater.*, **38**, 582-593.

Shariati, A., Shariati, M., Sulong, N.R., Suhatril, M., Khanouki, M.A. and Mahoutian, M. (2014a), "Experimental assessment of angle shear connectors under monotonic and fully reversed cyclic loading in high strength concrete", *Constr. Build. Mater.*, **52**, 276-283.

Shariati, M., Shariati, A., Sulong, N.R., Suhatril, M. and Khanouki, M.A. (2014b), "Fatigue energy dissipation and failure analysis of angle shear connectors embedded in high strength concrete", *Eng. Fail. Anal.*, **41**, 124-134.

Shariati, M., Sulong, N.R., Shariati, A. and Khanouki, M.A. (2015), "Behavior of V-shaped angle shear connectors: experimental and parametric study", *Mater. Struct.*, **49**(9), 3909-3926.

Shariati, M., Sulong, N.R., Shariati, A. and Kueh, A.B.H. (2016), "Comparative performance of channel and angle shear connectors in high strength concrete composites: An experimental study", *Constr. Build. Mater.*, **120**, 382-392.

Shariati, M., Toghroli, A., Jalali, A. and Ibrahim, Z. (2017), "Assessment of stiffened angle shear connector under monotonic and fully reversed cyclic loading", *Proceedings of the 5th International Conference on Advances in Civil, Structural and Mechanical Engineering - CSM 2017*, Zurich, Switzerland.

Soty, R. and Shima, H. (2013), "Formulation for shear force–relative displacement relationship of L-shape shear connector in steel–concrete composite structures", *Eng. Struct.*, **46**, 581-592.

Tahmasbi, F., Maleki, S., Shariati, M., Sulong, N.R. and Tahir, M.M. (2016), "Shear capacity of C-shaped and L-shaped angle shear connectors", *PloS one*, **11**(8), e0156989.

Tahmasebinia, F., Ranzi, G. and Zona, A. (2012), "Beam tests of composite steel-concrete members: A three-dimensional finite element model", *Int. J. Steel Struct.*, **12**(1), 37-45.

Toghroli, A., Mohammadhassani, M., Suhatril, M., Shariati, M. and Ibrahim, Z. (2014), "Prediction of shear capacity of channel shear connectors using the ANFIS model", *Steel Compos. Struct., Int. J.*, **17**(5), 623-639.

Toghroli, A., Suhatril, M., Ibrahim, Z., Safa, M., Shariati, M. and Shamshirband, S. (2016), "Potential of soft computing approach for evaluating the factors affecting the capacity of steel–concrete composite beam", *J. Intel. Manuf.*, **29**(8), 1793-1801.

Valente, I. and Cruz, P. (2004), "Experimental analysis of Perfobond shear connection between steel and lightweight concrete", *Constr. Steel Res.*, **60**(3-5), 465-479.

Wei, X. and Xiao, L. (2013), "Mechanical behaviour and failure mechanism of perfobond shear connectors in steel-concrete hybrid structure", IABSE Symposium Report; International Association for Bridge and Structural Engineering.

Wei, X., Xiao, L. and Pei, S. (2017), "Experiment study on fatigue performance of perforated shear connectors", *Int. J. Steel Struct.*, **17**(3), 957-967.

Wei, X., Shariati, M., Zandi, Y., Pei, S., Jin, Z., Gharachurlu, S., Abdullahi, M.M., Tahir, M.M. and Khorami, M. (2018), "Distribution of shear force in perforated shear connectors", *Steel Compos. Struct., Int. J.*, **27**(3), 389-399.

Yasuda, S., Michikoshi, S., Kobayashi, Y. and Narihara, H. (2008), "Experimental study on shear strength of headed stud shear connectors at high temperature", *Struct. Constr. Eng.*, **73**(630), 1417-1433. [In Japanese]

Zhao, B. and Kruppa, J. (1995), *Fire Resistance of Composite Slabs With Profiled Steel Sheet and of Composite Steel Concrete Beams*, EU, EU publications.

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