



SHEAR AND FLEXURAL BEHAVIOR OF R.C. BEAMS STRENGTHENED WITH POLYUREA SPRAY

A. E. Marawan¹, A. S. Debaiky², N. N. khalil³

¹,Department of Civil Engineering, Faculty of Engineering, Egyptian Russian University, Egypt

^{2,3}Department of Civil Engineering, Banha Faculty of Engineering, Banha University, Egypt

ABSTRACT

Recent research was conducted to study the flexural and shear behavior of R.C beams strengthened externally by sprayed polyurea system. In addition, the effectiveness of changing the thickness of polyuria was studied. The technique of polyurea system to strengthen R.C beams was investigated in order to evaluate the increase in the flexure and shear capacity of beams. Small and large scale of beams was examined. Different strengthening schemes for beams were used with variable thickness of polyurea. Sixteen specimens were prepared and divided into six flexure beams and ten shear beams. The experimental results included ultimate load, vertical deflection along the beams, overall ductility, and containing fragmentation. The polyurea system showed measurable increase in flexure and shear capacity of beams. Moreover, the ductility of beams was increased. The ability of containing fragmentation was clearly achieved by polyurea coating.

Keywords: Beams Retrofitting, Ductility, Flexure Strength, Polyurea, Shear Strength

Abbreviations

LVDT-R: linear variable deformation transducer in the right side of specimen; **LVDT-L:** linear variable deformation transducer in the left side of specimen; **LVDT-C:** linear variable deformation transducer in the center of specimen; **LVDT-CL:** linear variable deformation transducer in the center span of specimen under left load point; **LVDT-CR:** linear variable deformation transducer in the center span of specimen under right load point; **VL:** vertical position; **HL:** horizontal position; **F:** Flexure Test, **SR:** Shear Test, with Stirrups, **SN:** Shear Test, without Stirrups, **S-C:** Small Scale Control Beam, **S-P:** Small Scale Beam with Polyurea, **L-C:** Large Scale Control Beam, **L-P:** Large Scale beam with Polyurea

I. INTRODUCTION

Reinforced concrete structures around the world are frequently subjected to greater challenges such as change of use, increase in the existing loads, and durability of aging structures. For that, rehabilitation, upgrading of structural members and maintenance, are more suitable way for increasing the serviceability of structural members. To cope with the great structural demands, many attempts of repairing and retrofitting methods have been developed to increase strength of RC beams. Steel plates or Fiber-Reinforced Polymers (FRP) is one of the external strengthening systems that can be used for RC beams. This research investigates a new external strengthening system that called "polyurea system" that would have a spray application rather than the



traditional manual layup method, further minimizing the repair time and effort required to complete the external strengthening.

Polyurea is an elastic polymer that is material from two-component. Polyurea bonds very quickly and evenly during application. Some of the characteristics of the Polyurea coating are chemical and water resistance, excellent elongation, and quick curing. Polyurea coating is capable of withstanding regular thermal or dynamic movement in common structure as well. Also, the material is not very sensitive to temperature and humidity during installation and service. Polyurea was used as coating material to prevent attack of corrosion to concrete structure, although used to strengthening the structure and containing spalling and reduce fragmentation from blast and repeated impacts.

Polyurea was used to protection from steel corrosion and QUV weathering test (Myers et al., and Zheng et al.,) [1]. The Polyurea retrofit approach or blast mitigation and impact resistance was investigated by conducting testing on masonry walls (Knox et al. 2000 [2]; Davidson et al. 2004 [3]; Johnson et al. 2004 [4]; Baylot et al. 2005 [5]; Davidson et al. 2005 [6]; Hrynyk and Myers 2007 [7]; Hrynyk and Myers 2008 [8]; Oesterle 2009 [9]; Tanizawa and Myers 2009 [10]; Myers and Tanizawa 2010 [11]), vehicle barriers (Coughlin 2008 [12]; Carey and Myers 2009a [14]), and reinforced concrete panels (Tinsley and Myers 2007 [13]; Viswanath 2007 [15]). Polyurea coating is capable of containing spalling and reducing fragmentation from blast and repeated impact (Tinsley and Myers 2007 [13]; Viswanath 2007 [15]; Carey and Myers 2009a [14]). The use of discrete fiber reinforced polyurea system showed increasing in flexure and shear capacity (Greene and Myers 2013 [16]). Polyurea also aids in confinement of post-blast materials in compression-loaded structures, which produces a residual load-bearing capability.

II. EXPERIMENTAL PROGRAM

2.1 Tested Specimens

Beams were designed and setup tests were produced to make failure of the beams was flexure or shear. Flexure beams consist of four small-scale R.C beams (F1, F2, F3, and F4), and two large-scale R.C beams (F5, and F6). Shear beams consist of eight small-scale R.C beams, where four beams (SR1, SR2, SR3, and SR4) were designed with shear reinforcement (stirrups) along the full span, and the others four beams (SN1, SN2, SN3, and SN4) were designed without shear reinforcement (no stirrups) along the full span to calculate accurately shear capacity provided by polyurea coating system, and two large-scale R.C beams (SR5, SR6).

The dimensions of tested specimens, reinforcement details and the cross section were different according to type of the beam. For all the beams, the top reinforcement was 2Ø8. But the bottom reinforcement for (F1, F2, F3, and F4) was 2Ø12, and the stirrups were 5 Ø6/m as shown in Fig (1). The bottom reinforcement for (SR1, SR2, SR3, and SR4) was 3Ø12, and the stirrups were 4Ø6/m as shown in Fig (2). The bottom reinforcement for (SN1, SN2, SN3, and SN4) was 3Ø12, and no stirrups were used as shown in Fig (3). The bottom reinforcement for (F5, and F6) was 3Ø12, and the stirrups were 2Ø6/m as shown in Fig (4). The bottom reinforcement for (SR5, and SR6) was 6Ø12, and the stirrups were 2Ø6/m as shown in Fig (5).

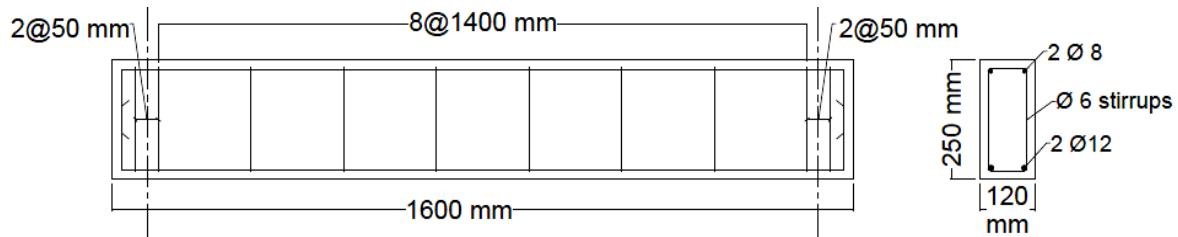


Fig (1): Flexure Beams (F1, F2, F3, and F4)

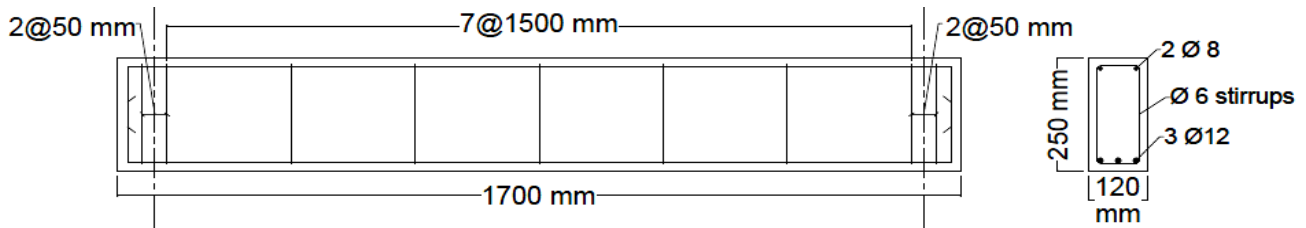


Fig (2): Shear Beams (SR1, SR2, SR3, and SR4)

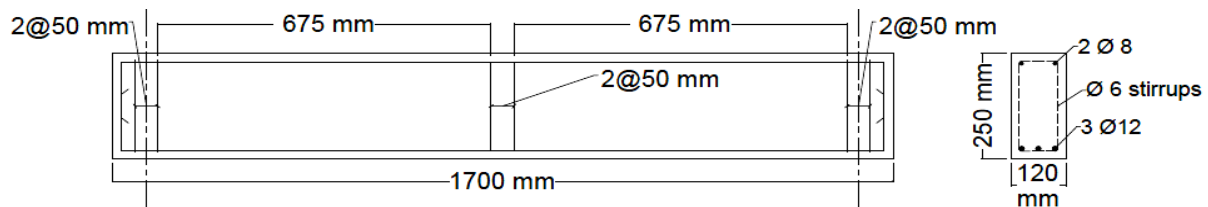


Fig (3): Shear Beams (SN1, SN2, SN3, and SN4)

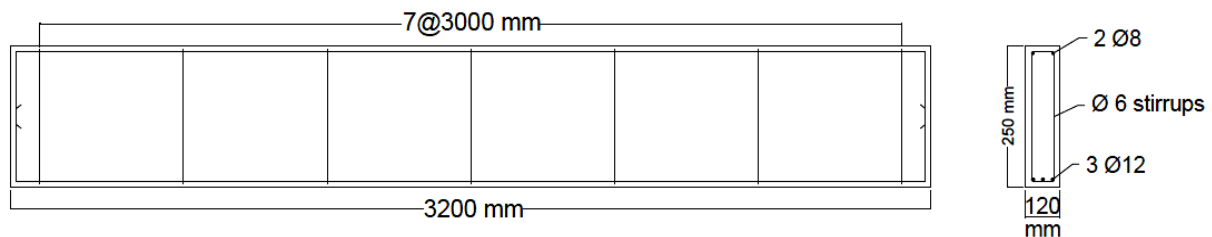


Fig (4): Flexure Beams (F5 and F6)

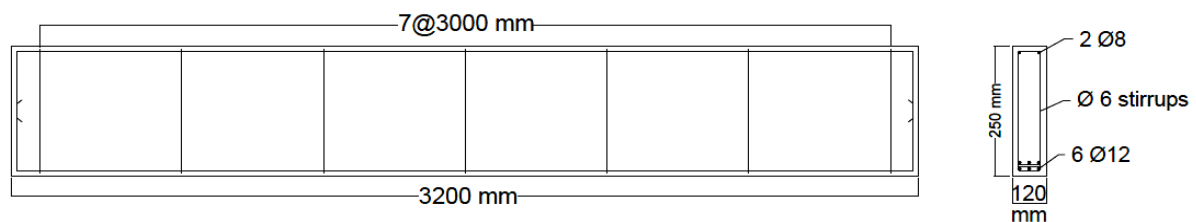


Fig (5): Shear Beams (SR5 and SR6)

After casting the beams, the beams were strengthened with polyurea spray. But the visual inspection done to determine and fix any faults, before spray polyurea to the surface of concrete. Free face of concrete affects hardly in bond of polyurea to concrete, so if there is any rough surface, it fix to be smooth. Finally, beams were exposed to direct sun light in open area to make sure clearance of beams surface from moisture to make a perfect bond between polyurea and concrete. After that, all of beams are ready to expose to polyurea spray as shown in Fig (6).

The scheme of strengthening the beams in flexure and shear differ according to scale of beams and the type of failure. In small-scale beam, polyurea covered whole beam with different thickness as shown in Figure (7). For beams (F1, F2, F3, and F4), the beam F1 was used as a control flexure beam and the beams (F2, F3, and F4) were strengthened with 2, 4, and 6 mm thick. respectively. For beams (SR1, SR2, SR3, and SR4), the beam SR1 was used as a control shear beam and the beams (SR2, SR3, and SR4) were strengthened with 2, 4, and 6 mm thick. respectively.



Fig (6): Spray of Polyurea



Fig (7): Scheme of Polyurea in Small- scale Beams

For beams (SN1, SN2, SN3, and SN4), the beam SN1 was used as a control shear beam and the beams (SN2, SN3, and SN4) were strengthened with 2, 4, and 6 mm thickness respectively.

But, in large scale beams the polyurea covered the predicted area of failure where beams will fail. For the beam (F5, and F6), the beam F5 was used as a control flexure beam and the beam F6 was strengthened with 5 mm thickness where polyurea covered distance equal 1.5 m at mid span (75 cm left and right from center line of beam), and For the beam (SR5, and SR6), the beam SR5 was used as a control flexure beam and the beam SR6 was strengthened with 5 mm thickness, polyurea sprayed at ends of beams only for distance 1m from each end as shown in Fig (8).



Fig (8): Scheme of Polyurea for shear beam (SR6)

2.2 Materials

Material testing was done to determine the mechanical properties of polyurea spray as mentioned in Table (1). Tension test and tearing-off test was performed. Test specimens lay out were illustrated in Fig (9).



Fig (9): Test Specimens Layout

For the concrete, the maximum aggregate size used was 20-mm. Nominal concrete mix was used to achieve the strength of 25 MPa. The water /cement ratio was 0.45. The three cube (15x15x15) cm³ were casted and tested at the time of testing beams. The average compressive strength of the concrete was 29 MPa at testing of beams. The longitudinal reinforcements used were high-tensile deformed bars of 12 mm diameter. The stirrups were made from mild steel bars with 6 and 8 mm diameter. The yield strength of steel reinforcement used in experimental program was determined by performing the standard tensile test. The average proof stress at (0.2 %) strain of 12 mm diameter was 400 MPa and yield stress of 6 and 8 mm diameter was 240 MPa.

Table (1): Mechanical Properties of Polyurea

Property	units	value	specification
Density	N / m ³	10.30	DIN 53420
Tensile strength	N / mm ²	12.98	DIN 53420
Elongation at break	cm	37	DIN 53420
Tear strength	N / mm	93.2	DIN 53515
Gel time	Seconds	15	_____
Take free time	Seconds	85	_____
Full curing time	Hours	48	_____

Table (2):Summary of Tested Specimens

Beam	Beam Type	Polyurea Thick.(mm)
F1	S-C	0
F2	S-P	2
F3	S-P	4
F4	S-P	6
F5	L-C	0
F6	L-P	5
SR1	S-C	0
SR2	S- P	2
SR3	S-P	4
SR4	S-P	6
SR5	L-C	0
SR6	L-P	5
SN1	S-C	0
SN2	S-P	2
SN3	S-P	4
SN4	S-P	6

3. Testing Setup and Procedure:

All specimens were tested in testing frame of reinforced concrete research laboratory of Faculty of Engineering, Banha University as shown in fig (10).



Fig (10): Frame Used in Testing Beams

Beams were tested using different loading set up to produce the required failure mechanism (flexure or shear failure). The load was applied by a hydraulic jack connected with braced steel frame which has a capacity of 100 ton. The different spread beams were used to create 2-points loading. The loading set up was different according to scale of the beams and type of failure. The load in small-scale flexure beams was applied at 2-points by using

spread steel beam where the distance between the 2-points was 200 mm. The supports were placed at 75 mm from each end of beam as shown in Fig (11).the load in small-scale shear beams was applied at 2-points by using spread steel beam where the distance between the 2-points was 1000 mm. The supports were placed at 75 mm from each end of beam as shown in Fig (12). The load in large-scale flexure beams was applied at 2-points by using spread steel beam where the distance between the 2-points was 500 mm. The supports were placed at 100 mm from each end of beam as shown in Fig (13). The load was applied at 2-points by using spread steel beam where the distance between 2-points was 1650 mm. The supports were placed at 100 mm from each end of beam as shown in Fig (14).

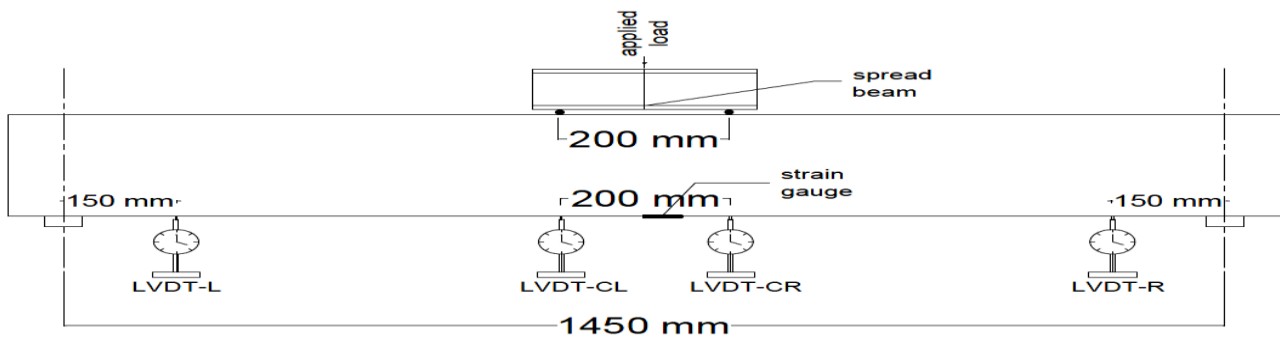


Fig (11): Experimental Setup of flexure beams (F1, F2, F3, and F4)

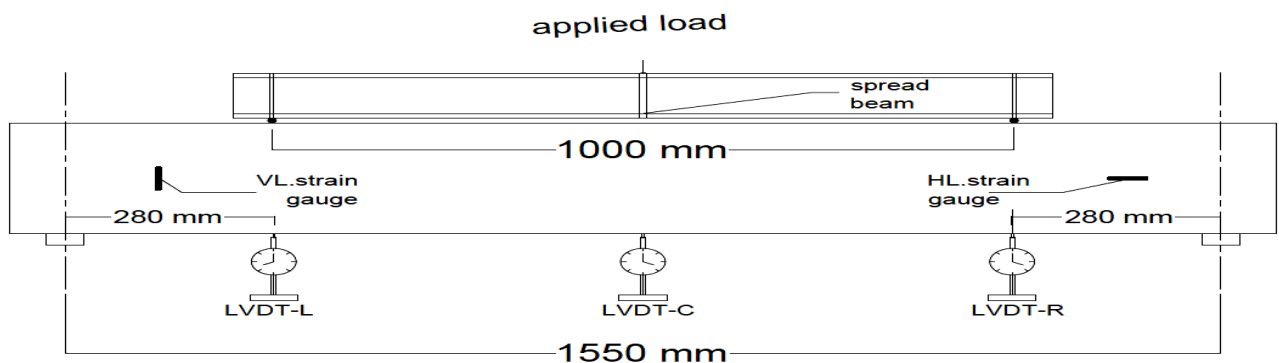


Fig (12): Experimental Setup of Shear Beams (SR1, SR2, SR3, and SR4)

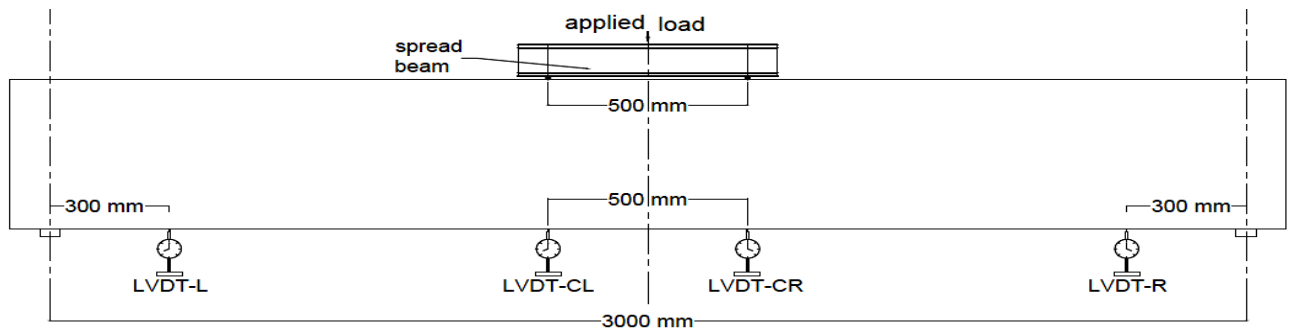


Fig (13): Experimental Setup of Flexure Beams (F5, and F6)

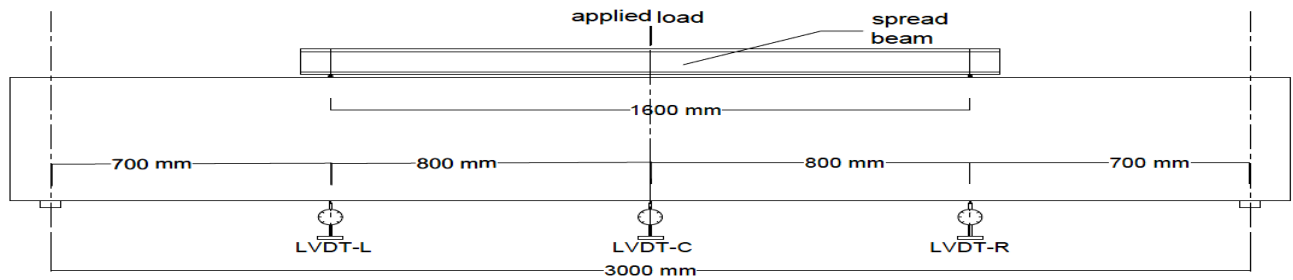


Fig (14): Experimental Setup of shear Beams (SR5, and SR6)



Fig (15): Testing of Shear Beam (SR5)



Fig (16): Testing of Flexure Beam (F3)

IV. EXPERIMENTAL RESULTS AND DISCUSSION

4.1 Ultimate Load

The ultimate capacity of each beam was determined by the peak load attained during loading test and listed in table (3). The data collected to determine the validity of polyurea coating in retrofitting the ultimate capacity of beams. For flexural beams (F1, F2, F3, and F4), the Fig (17) show comparison between the ultimate load of each beam and for flexural beams (F5, F6), Fig (18) show comparison between the ultimate load of each beam. All flexural beams show flexure failure by crushing the concrete in compression zone. the beam F1, as expected from design according to Egyptian Code the peak load of small control beam was 87.78 KN while the beam F2 with 2 mm thickness of polyurea was failed at 92.6 KN that showed increasing in peak load about 6.1 % (5.4 KN Gained), the beam F3 with 4 mm thickness of polyurea was failed at 97.1 KN that showed increasing in peak load about 10.6 % (9.3 KN Gained), and the beam F4 with 6 mm thickness of polyurea was failed at 104.8 KN that showed increasing in peak load about 19.4 % (17 KN Gained).

Although, in large flexural beams, the beam F5 as expected from design according to Egyptian Code the peak load of large control beam was 118.1 KN while the beam F6 with 5 mm thickness of polyurea was failed at 131.3 KN that showed increasing in peak load about 11.2% (13.2 KN Gained).

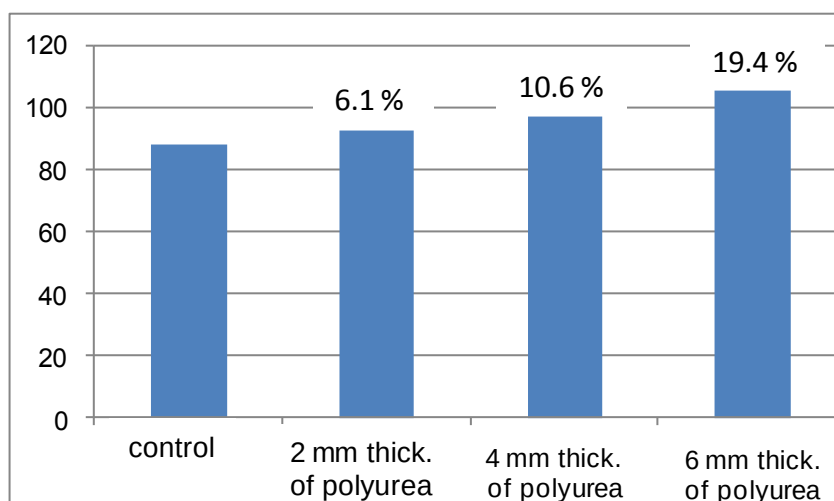


Fig (17): Ultimate Load Comparison of Flexural Beams (F1, F2, F3, and F4)

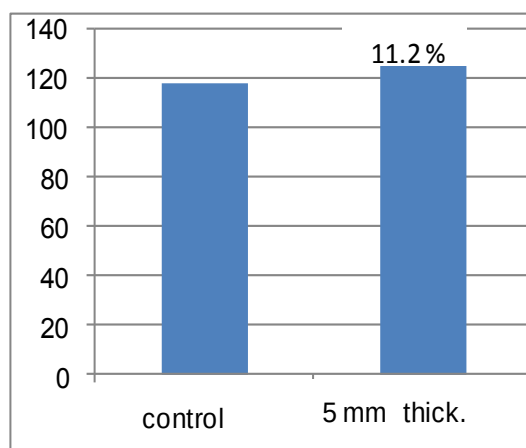


Fig (18): Ultimate Load Comparison of Flexural Beams (F5, and F6)

For shear beams (SR1, SR2 SR3, and SR4), the Fig (19) show comparison the ultimate load of each beam and for shear beams (SR5, and SR6), the Fig (20) show comparison the ultimate load of each beam. Almost of beams showed shear failure by diagonal tension cracks, and showed measurable increasing in ultimate load. In small reinforced shear beams, the beam SR1 as expected from design according to Egyptian Code the peak load of small control beam was 118.36 KN while the beam SR2 with 2 mm thickness of polyurea was failed at 122.25 KN that showed increasing in peak load about 3.5 % (3.9 KN Gained) but unfortunately the beam failed by support failure not shear failure, the beam SR3 with 4 mm thickness of polyurea was failed at 147.73 KN that showed increasing in peak load about 24.8 % (29.4 KN Gained), and the beam SR4 with 6 mm thickness of polyurea was failed at 168.68 KN that showed increasing in peak load about 42.5 % (50.3 KN Gained). The small non-reinforced beam showed increasing in ultimate load as shown in Fig (21).

Although, in large shear beams, the beam SR5 as expected from design according to Egyptian Code the peak load of large control beam was 204.26 KN where the beam SR6 with 5 mm thickness of polyurea was failed at 261.89 KN that showed increasing in peak load about 28.2 % (57.6 KN Gained)

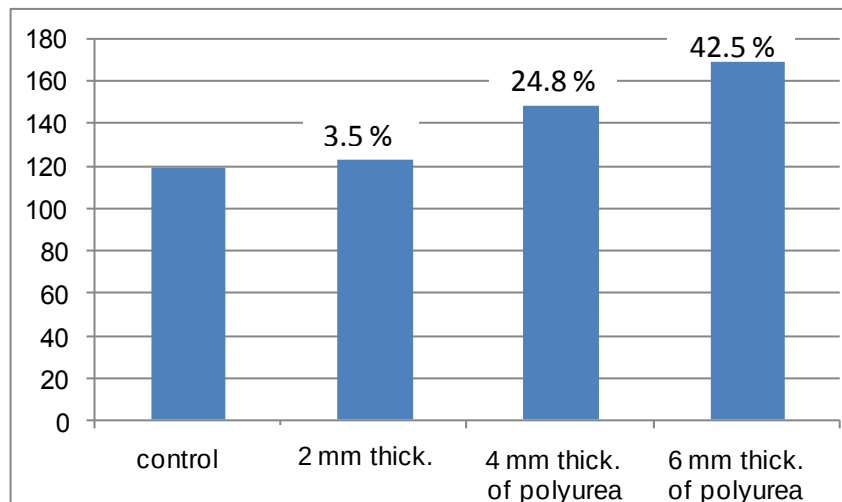


Fig (19): Ultimate Load Comparison of shear Beams (SR1, SR 2, SR 3, and SR 4)

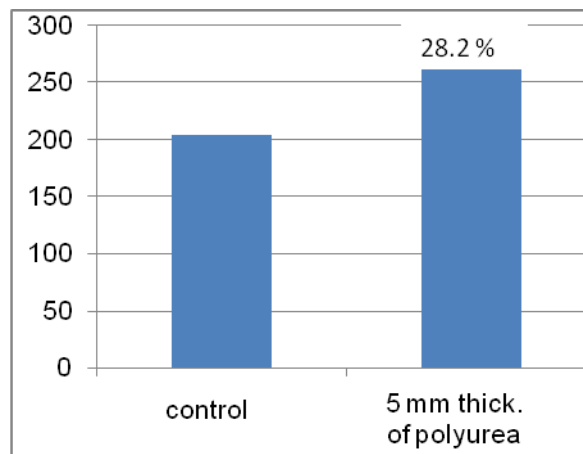


Fig (20): Ultimate Load Comparison of shear Beams (SR5, and SR 6)

Table (3): Summery of Gained Strength for Specimens

Beam	Gained Strength (KN)
F2	5.4
F3	9.3
F4	17
F6	13.2
SR2	3.9
SR3	29.4
SR4	50.3
SR6	57.6
SN2	18
SN3	29
SN4	51

4.2 Deflection and Ductility

Another important parameter was appeared during the testing of beams was deflection and ductility. All beams were showed increased in ductility and more deflection prior to failure of beam. The load-deflection curved showed that the thicker coating gives the largest increase in ductility and more deflection. Fig (21) to Fig (24) shows the load-deflection of all beams. Deflection of the polyurea beams was greater than that of the control beam, so relative ductility was measured to compare between the gained ductility for each beam. The ductility was measured by the area under each beam load-deflection curve. The Area represented the ductility, was estimated up to the point of failure of the beam, when the beam could no longer carry load, and the load-deflection curve thus showed a marked drop. This ductility value for each beam was then divided by the area under the load-deflection curve of the control beam, to obtain a load-deflection based ductility index, DI. Table (4) showed some value of ductility index.

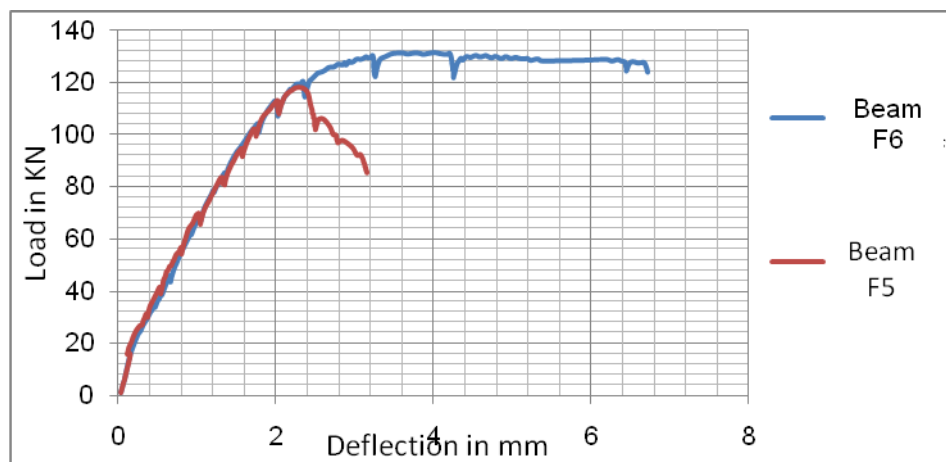


Fig (21): Load-Deflection of Large Flexure Beams (F5, and F6)

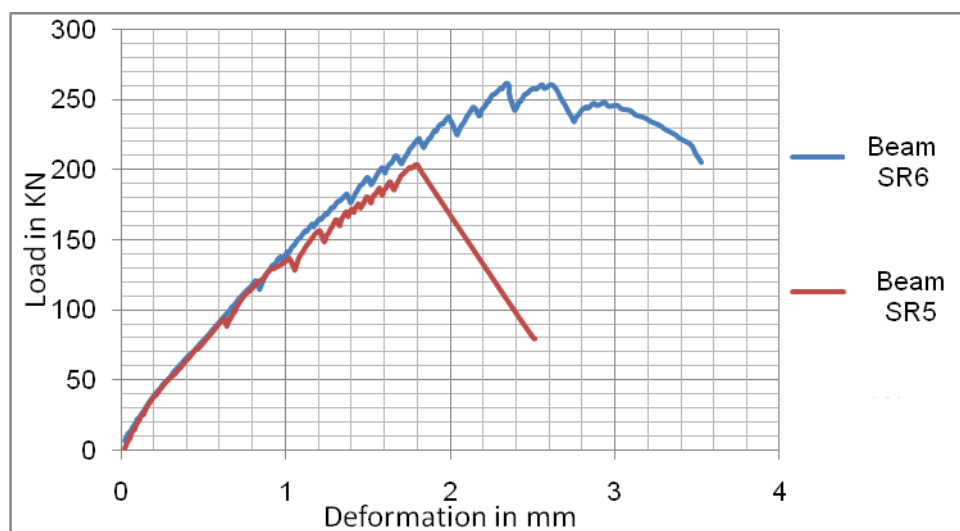


Fig (22): Load-Deflection of Large Shear Beams (SR5, and SR6)

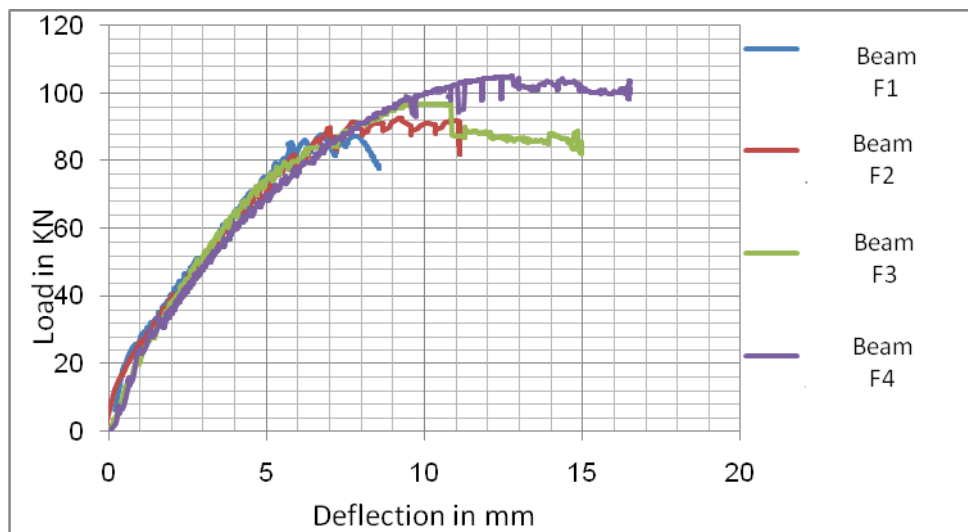


Fig (23): Load-Deflection of Small Flexure Beams (F1, F2, F3, and F4)

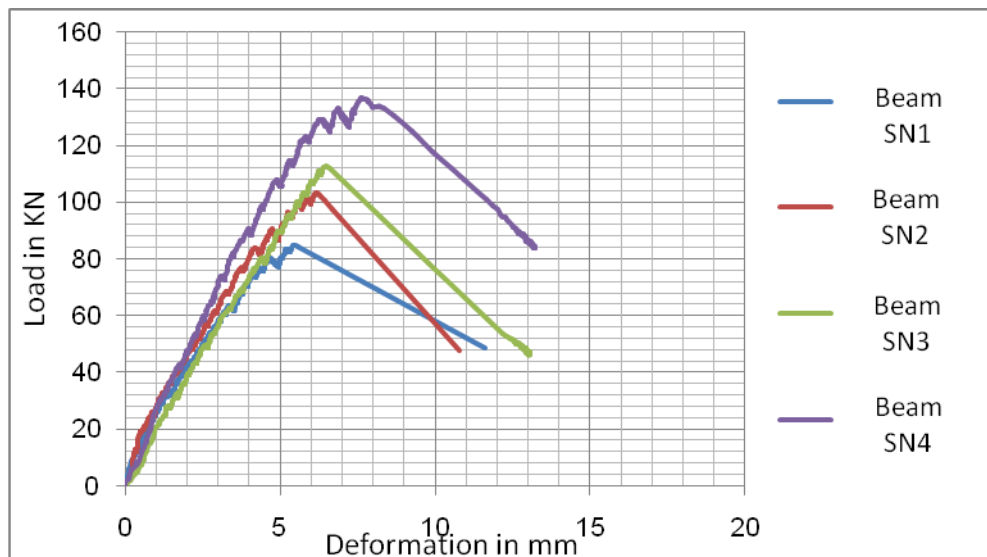


Fig (24): Load-Deflection of Small Non-Rein. Shear Beams (SN1, SN2, SN3, and SN4)

Table (4): Ductility Index for Flexural and Shear Beams

Beam	Area under curve(KN.mm)	Ductility Index
F1	300	1
F4	850	2.83
F5	143	1
F6	396	2.76
SR1	236	1
SR4	510	2.16
SR5	180	1
SR6	351	1.95

Another important parameter was containing the fragmentation. This property appeared obviously in non-reinforced shear beam as shown in Fig (25).



(A) :(Beam SN1)



(B): (Beam SN4)

Fig (22): Containing of Fragmentation of Non-Rein. Shear Beam (SN1, and SN4)

V. CONCLUSION

Based on the investigation and experimental results described, a number of conclusions may be considered for polyurea coating system. The findings are summarized below.

1. In general, Polyurea provided greater ease of application, make beams more ductility, and act as containing material where fragmentation was reduced.
2. The polyurea coating systems provided additional flexural reinforcement that resulted in ultimate capacities where the ultimate load was increased by 19.4 % for small beams and 11.2 % in large beams
3. The polyurea coating systems provided additional shear reinforcement that resulted in ultimate capacities where the ultimate load was increased by 42.5 % for small beams and 28.2 % in large beams
4. Polyurea showed more increase in load for shear beams than flexure beam that refer to polyurea act as confinement material as well.
5. The ductility of polyurea-coated beams, as opposed to non-coated beams, was substantially greater. Polyurea increase the ductility of beams as mentioned in table ().



6. The polyurea coating systems showed more deflection during concrete failure so more warning and saving of lives before failure.

REFERENCES

- [1]. Myers, J. and Zheng, W. (2011) Modern Protection Systems to Prevent Corrosion of Structural Steel Elements Due to Deicing and Roadway Salts. ASCE Journal of Design, Construction, Rehabilitation, and Maintenance of Bridges: pp. 121-128.doi: 10.1061/47630(409)16
- [2]. Knox, K. J., Hammons, M. I., Lewis, T. T. & Porter, J. R. (2000). "Polymer Materials for Structural Retrofit". (Report). Florida: Force Protection Branch, Air Expeditionary Forces Technology Division, Air Force Research Laboratory, Tyndall AFB.
- [3]. Davidson, J. S., Porter, J. R., Dinan, R. J., Hammons, M. I. & Connell, J. D. (2004). "Explosive Testing of Polymer Retrofit Masonry Walls". Journal of Performance of Constructed Facilities, Vol. 18, No. 2: pp. 100-106
- [4]. Johnson, Carol F., Slawson, Thomas R., and Cummins, Toney K. (2004). "Concrete Masonry Unit (CMU) Static and Dynamic Wall Experiments with Elastomeric Retrofits." US Army Engineer Research and Development Center (EDRC)
- [5]. Baylot, J.T., Bullock, B., Woodson, S.C., and O'Daniel, J.L., "Blast Response of Lightly Attached CMU Walls," ASCE Journal of Structural Engineering, v 131, n8, August 2005, pp. 1186-1193
- [6]. Davidson, J. S., Fisher, J. W., Hammons, M. I., Porter, J. R. & Dinan, R. J. (2005). "Failure Mechanisms of Polymer-Reinforced Concrete Masonry Walls Subjected to Blast". Journal of Structural Engineering, Vol. 131, No. 8: pp. 1194-1205.
- [7]. Hrynyk T. D. and Myers J.J., "Static Evaluation of the Out-of-plane Behavior of URM Infill Walls Utilizing Modern Blast Retrofit Systems," Center for Infrastructure Engineering Studies Report, University of Missouri-Rolla, Rolla, Missouri, 2007.
- [8]. Hrynyk, T. D., and Myers, J. J. (2008). "Out-of-plane behavior of URM arching walls with modern blast retrofits: Experimental results and analytical model." J. Struct. Eng., 134(10), 1589–1597.
- [9]. Magallanes, J.M., Morrill, K.B., Crawford, J.E., Oesterle, M.G. and Hegemier, G.A. (2008). "Finite element models for the analysis and design of CMU walls to blast loads". in 2008 Department of Defense Explosives Safety Seminar. Palm Springs, CA.
- [10]. Tanizawa, Y., Myers, J.J., and Sinclair, R., "In-plane Response of an Alternative URM Infill Wall System with and without a Polyurea Retrofit," FRPRCS-9 Proceedings, Sydney, Australia, July 2009.
- [11]. Myers, J. J., and Tanizawa, Y. (2010). "In-plane behavior of an alternative masonry retrofitted with polyurea membranes." Structural Faults and Repair (SF&R 2010) (CD-ROM), Edinburgh, Scotland, UK.
- [12]. Coughlin, A., 2008, "Contact Charge Blast Performance of Fiber Reinforced and Polyurea Coated Concrete Vehicle Barriers," Master's thesis, Pennsylvania State University, University Park, PA, 123 pp.
- [13]. Tinsley, M. and Myers J.J., "Investigation of a High-Volume Fly Ash-Wood Fiber Material Subjected to Low-Velocity Impact and Blast Loads," Center for Infrastructure Engineering Studies Report, University of Missouri-Rolla, Rolla, Missouri, 2007.



- [14]. Carey, N.L. & Myers, J.J. 2009a. "Full scale blast testing of hybrid barrier systems". American Concrete Institute (ACI) Special Publication Journal.
- [15]. Viswanath, T., 2007, "Experimental Study on the Impact Resistance of Polyurea Coated Concrete," Master's thesis, Pennsylvania State University, University Park, PA, 69 pp.
- [16]. Greene,. and Myers,. (2013). "Flexural and Shear Behavior of Reinforced Concrete Members Strengthened with a Discrete Fiber-Reinforced Polyurea System."