Ministry of Higher Education
And Scientific Research
University of Diyala
College of Engineering

FLEXURAL BEHAVIOR OF TEXTILE REINFORCED ONE-WAY SLAB MORTAR

A Thesis Submitted to Council of College of Engineering, University of Diyala in Partial Fulfillment of the requirements for the Degree of Master of Science in Civil Engineering

By

Omar Hamid Hussein

(B.Sc. In Civil Engineering, 2014)

Supervised by

Prof. Dr. Amer M. Ibrahim

Asst. Prof. Dr. Suhad M. Abd

2019 - October IRAQ 1440 - Sufar

COMMITTEE DECISION

We certify that we have read the thesis entitled **(Flexural Behavior of Textile Reinforced One-Way Slab Mortar)** and we have examined the student **(Omar Hamid Hussein)** in its content and what is related with it, and in our opinion, it is adequate as a thesis for the degree of Master of Science in Civil Engineering.

Examination Committee **Signature**

Prof. Dr. Amer M. Ibrahim (Supervisor)…….………………….……….

Dr. Suhad M. Abd (Co-Supervisor)……………….…………

Assist. Prof. Dr. Wissam D. Salman (Member)……........………………

Assist. Prof. Dr. Mohammed Mahmood (Member)…………………….

Prof. Dr. Aziz Ibrahim Abdulla (Chairman)…………….…………

Prof. Dr. Khattab Saleem Abdul-Razzaq …………………… (Head of Department)

The thesis was ratified at the Council of College of Engineering / University of Diyala.

Signature…………..……………

Name: Prof. Dr. Anees Abdullah Khadom

Dean of College of Engineering / University of Diyala

Date:

بسم الله الرحمن الرحيم

وقل ربي زدني علما

(سورة طه ١١٤)

DEDICATION

To my parents, especially my dead father who encouraged me till his last moments and my brothers and sisters with love and gratitude

ACKNOWLEDGEMENTS

Eternal praise and thanks are to Almighty Allah for His continuous infinite graces of which this thesis is a little one.

My deep respect and gratitude goes readily to my supervisors: ***Prof. Dr. Amer M. Ibrahim*** *and* ***Asst. Prof. Dr. Suhad M. Abd*** *who embodied their loyalty and meticulous care in reading just to weed out in accuracies without their help this study would have remained just a thread of an idea. My deep thanks to* ***Asst. Prof. Dr. Fahed Alrshoudi*** *from King Saud university for his continual consultation support.*

Inexpressible thanks go to the department of civil engineering and the staff of the Structural Engineering Laboratory, specially ***Eng. Hutheifa*** *and* ***Mr. Yass*** *for their invaluable guidance and unique remarks.*

My special thanks to the staff of the laboratory of Diyala company for electrical industries, specially ***Eng. Buraq and Mr. Ahmed***

Deep thanks to all my colleagues and friends who supported me fulfil this work.

Omar Hamid Hussein

2018

Flexural Behavior of Textile Reinforced One-Way Slab Mortar

By

Omar Hamid Hussein

Supervised by

Prof. Dr. Amer M. Ibrahim

Asst. Prof. Dr. Suhad M. Abd

ABSTRACT

Textile reinforced mortar that has developed in recent years is composed of the continuous textile fabric incorporated into the cementitious matrix. The excellent characteristics of the textile reinforcement such as high tensile strength, high modulus of elasticity and bond nature with the mortar promotes the use of this type of reinforcement instead of the steel reinforcement or with the steel reinforcement in reinforcing the mortar.

In this thesis the experimental and analytical investigation is carried out to study the flexural behavior of the textile reinforced and the composite (steel and textile) reinforced one-way slab mortar. Twelve one-way slabs with dimensions of (1500×500×50) mm were casted, cured and tested in flexure. Eight of the tested slabs were reinforced with the textile carbon fabric, one with steel reinforcement, one with chopped carbon fibers and two slabs were reinforced with steel in combination with one and two textile reinforcement layers.

The experimental results exhibited that the first crack load for the composite (steel with one and two layers of carbon textile reinforcement) slabs increased by (74.2% and 190%) respectively as compared with the slab

reinforced by only the steel reinforcement. As the load of steel reinforcement yielding increased by (115% and 91.5%) and the ultimate load increased by (66% and 103%) respectively as compared with the steel reinforced mortar one-way slab. Furthermore, the crack width is reduced by (67% and 29.4%) respectively at the cracking and at the final stage of loading. Furthermore, the mode of failure is changed from the brittle to the ductile with the combined textile reinforcement. However, increase the area of the textile reinforcement by increasing the number of layers increases the ultimate load by (32%−60.6%) and increase the mid span deflection at this point by (18.7%−37.9%) while the bond factor is reduced by (9.6%−24.84%) with the increase in number of layers. Moreover, the results showed that the (66.67%) removing of weft yarns represents the optimal percentage of removing since the cracking load and ultimate load were increased by (15.85% and 40.72%) respectively, while the mid span deflection at the ultimate load is reduced by about 6.09% as compared with the reference textile reinforced mortar one-way slab. Furthermore, the cracks number and the crack width have remained the same. The addition of the short carbon fibers by (0.25% and 0.5%) leads to increase the ultimate load by (24.19%−31.56%), bond factor by (24.69%−32.22%) while, the ultimate deflection reduced by (11.96% −16.31%) as compared with the control Textile reinforced mortar slab. The results exhibit the superior flexural behavior of the slab that reinforced by textile carbon layers as compared with the slabs reinforced steel reinforcement or short carbon fibers.

On the other hand, the results showed the mutual cooperative contribution between the steel and textile reinforcement in bearing the applied stresses.

LIST OF CONTENTS

LIST OF FIGURES

LIST OF PLATES

LIST OF TABLES

LIST OF SYMBOLS

Symbol	Definition
F_{ctu}	Tensile Strength of TRM MPa
f_t	Filament Tensile Strength MPa
k_1	Efficiency Factor
$k_{0,\alpha}$	Factor of Reinforcement Orientation
k_2	Biaxial Load Factor
$k_{fl,p}$	Factor for Bending Loading
kb	Factor Represents The Textile Area That in Good Contact with Matrix
ks	Strain Lag Factor between The Inner and Outer Yarn Filaments
z	Internal Lever Arm m
F_{tex}	Textile Reinforcement Resistance Capacity MPa
A_f	Total Area of the Textile Reinforcement
E_f	Fibrous Material Modulus of Elasticity
$\mathcal{E}_{f,max}$	Maximum Strain (i.e. strain of sleeve filaments)
$\mathcal{E}_{fu}$	Ultimate Tensile Strain of the Yarn
V_c	Shear Strength of the Mortar kN
ρf	Fiber Reinforcement Ratio
b	Width of The Section mm
d	Effective Depth of the Section mm
$Ø_y$	Curvature of the Section at the Yield of the Steel reinforcement
$Ø_u$	Curvature of the Section at the ultimate load
M_{cr}	Cracking Moment kN.m
M_{sd}	Design Nominal Moment kN.m
Ø	Mid Span Section Curvature
l	Span Length Between the Supports m
η_τ	Bond Efficiency Factor
$\mathcal{E}_c$	Mortar Strain
$\mathcal{E}_{c0}$	Extreme Value of Axial Compressive Strain at f'_c
$\mathcal{E}_u$	Ultimate Tensile Strain
β_1	Whitney Block Ratio
α_1	Ratio Between The Assumed Rectangular Stress Block and The Axial
f'_c	Compressive Strength of The Mortar
A_s	Area of Steel Reinforcement mm^2
f_y	Steel Reinforcement Yield Tensile Strength MPa
A_f	Area of Textile Reinforcement mm^2
f_u	Textile Reinforcement Tensile Strength MPa
h_0	Effective Depth of Steel Reinforcement mm

ξ_{b2}	Ratio of the neutral axis Depth to the Effective Depth of the Steel Reinforcement	
h_c	Depth of Compression Zone	mm
h_f	Effective Depth of Textile Reinforcement	mm
f_t	Splitting Tensile Strength	MPa
P	Failure Load	kN
D	Diameter of Cylinder	mm
L	Length of cylinder	mm
f_r	Modulus of rupture	MPa
P	Failure load	kN
L	Span Length between Supports Center to Center	m
b	Width of Prism Cross Section	mm
h	Depth of Prism Cross Section	mm
Ec	Modulus of Elasticity of Mortar	MPa
σ2	Stress Corresponding to 40 % of Ultimate Load	MPa
σ1	Stress Corresponding to Longitudinal Strain 0.00005	
ϵ_2	Longitudinal Strain Produced by Stress σ2	
τ_e	Pull out Stress	Mpa
r	Yarn Radius	mm
h	Embedded Depth of the Yarn	mm
Lemb	Embedded Length	mm
Smax	Total Displacement	mm
δmax	Pull out Displacement	mm
A_T	Area of Textile Reinforcement	mm2
Ɛu	Ultimate Compressive Strain of Mortar	
ε_y	Yielding Strain of The Steel	
ε_s	Steel Tensile Strain	
P_u	Ultimate Load	kN
$P_{0.001}$	Load at 0.001 Mortar Compressive Strain	
Δu	Mid Span Deflection at Ultimate Load	mm
Δy	Mid Span Deflection at Steel Yield	mm
V_T	Volume of Textile Fibers	
V_{crit}	Critical Volume of Textile Fibers	
V_f%	Volumetric Ratio	
I_g	Gross Moment of Inertia	mm^4
I_{cr}	Cracked Moment of Inertia	mm^4
I_{eff}	Effective Moment of Inertia	mm^4
Φ_{cr}	Curvature at the Cracking	
Φ_u	Ultimate Curvature	
V_{CF}	Volume of Carbon Fibers	
V_F	Total Volume of Fibers	

LIST OF ABBREVATIONS

Abbreviation	Definition
FRP	Fiber Reinforced Polymer Bars
TRM	Textile Reinforced Mortar
FRMCs	Fiber Reinforced Cementitious Composites
AR glass	Alkali Resistant Glass
FRM	Fiber Reinforced Mortar
GFRM	Glass Fiber Reinforced Mortar
SRM	Steel Reinforced Mortar
GMBH	Gesellschaft Mit Beschränkter Haftung: Company with Limited Liability
PE	Polyethylene
PP	Polypropylene
PVA	Polyvinyl-Alcohol
RWTH	Rheinisch-Westfälische Technische Hochschule
SLS	Serviceability Limit State
ULS	Ultimate Limit State
SRM	Steel Reinforced Mortar
SRM+1T	Steel Reinforced Mortar + One Textile Layer
SRM+2T	Steel Reinforced Mortar + Two Textile Layers
TRM 4L	Textile Reinforced Mortar with Four Layers
TRM 6L	Textile Reinforced Mortar with Six Layers
TRM 8L	Textile Reinforced Mortar with Eight Layers
TRM 50 % R.W.Y	Textile Reinforced Mortar with 50% Removed Weft Yarns
TRM 66.67% R.W.Y	Textile Reinforced Mortar with 66.67% Removed Weft Yarns
TRM 75% R.W.Y	Textile Reinforced Mortar with 75% Removed Weft Yarns
TRM+0.25%SCF	Textile Reinforced Mortar with 0.25% Short Carbon Fibers
TRM+0.5%SCF	Textile Reinforced Mortar with 0.5% Short Carbon Fibers
ASTM	American Society for Testing and Material
MEKP	Methyl Ethyl Ketone Peroxide
PAN	PolyAcryloNitrile
SFB	SonderoFrschungs Bereich: Collaborative Research Center
ACI	American Mortar Institutes
CAN/ CSA	Canadian Standards Association

CHAPTER ONE

INTRODUCTION

1.1 General

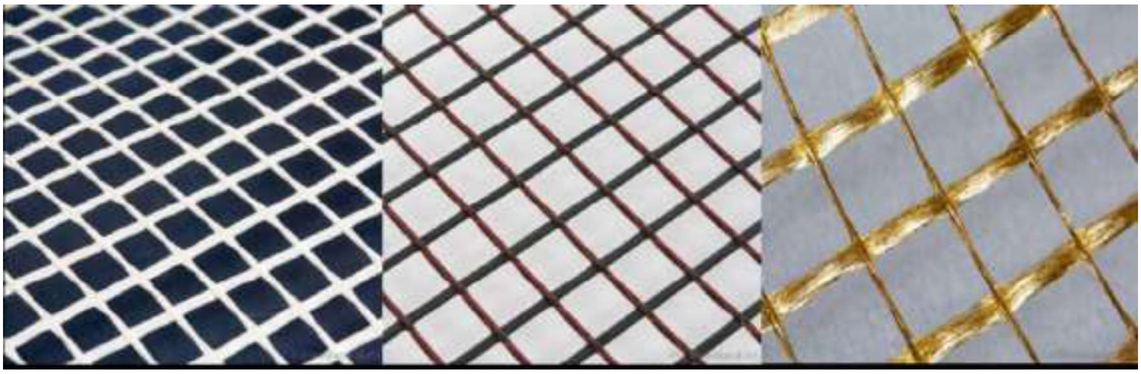
The middle of the 19th century represents the beginning of the conventional reinforced concrete utilization in the structural applications (**Shaeffer**, 1992). However, investigation and development regard this construction material continues to this day. The concrete low tensile strength necessitates the steel bars utilization in the aim of compensating the concrete low tensile strength. The sensitivity of the steel reinforcement to corrosion leads to the damage in structural integrity in case of concrete weakness (**Domone**, 2010). Due to this corrosive nature, a precautionary thick concrete cover is necessary to overcome this issue regardless the self weight excess. The use of stainless steel bars, fiber reinforced polymer (FRP) bars, steel and synthetic fibers, epoxy coated steel bars and steel welded wire fabric is coming to overcome this issue (**Nmai**, 2006).

"Textile reinforced concrete (TRC) is a new kind of fiber reinforced cementitious composites (FRCCs)" (**Pakravan** et al. 2015) composed of fine grained cement-based matrix reinforced by multiaxial textile reinforcement. The excellent properties of the textile reinforcement including the superior tensile strength, high modulus of elasticity in addition to the non corrosive nature made it quite adequate in producing plane wings by Boeing Aircraft Company since 1920s. Engineering applications, utilized Textile reinforced composites for many years. The interest in textile reinforcement was continued since the early 1970s (**Mobasher**, 2011). The modern composite material was inclusively investigated by the collaborative research centers at Dresden University of Technology and 532 and 528 at RWTH Aachen Unive

-rsity (**Orlowsky**, 2011). The excellent properties of the textile reinforcement encouraged the use of this type of reinforcement instead of the conventional steel reinforcement. Textiles are unlike chopped fibers that distributed randomly in the cementitious matrix. The chopped fibers do not resist the tensile stresses efficiently because of their closely spaced tendency compared to conventional reinforcing bars, however they are better in controlling the cracking (**Bentur** and **Mindess**, 2006) i.e. these discontinuous fibers can be used as secondary reinforcement. However, the fibers like an AR (Alkali resistant) glass and carbon fibers are used for decades as a strengthening technique to rehabilitate the RC structural members. The fiber materials are resistant to corrosion that leads to reduce the cover dimensions and then the thickness of the structural element is minimized (**Keil** et.al, 2008).

1.2 Textile Reinforced Concrete (TRC)

Textile reinforced concrete (TRC) is a novel composite material made by incorporating the continuous textile fabric into the fine grained concrete that consisting of a cement binder and fine aggregates. **Jesse** (2003) stated that the concrete is functionally represented by the matrix with the lowest 90% or usual volume of 95% to 99%, however the composite low tensile strength is compensated by the textiles. Since the type of concrete that must be used in textile reinforced concrete production if a fine grained i.e. with a minimum aggregate size hence the concrete matrix is closer to be a mortar and it may have called textile reinforced mortar (TRM). Utilization of textile reinforced concrete acquires several interests. TRC has demonstrated high efficiency in specific, high durability and strength performance. The textile reinforcement and fine grained concrete are shown in Figures (1-1) and (1-2) respectively.



AR-glass **Carbon** **Basalt**

Figure (1-1): Examples of Textile reinforcements (Portal, 2015)

Figure (1-2): Mortar

Textile reinforced concrete (TRC) differs from fiber reinforced concrete (FRC) for the reason that it can be positioned where the stresses occur (**Alrshoudi**, 2015). **Papanicolaou** and **Papantoniou** (2010) mentioned that the textile reinforcement properties can be fully employed as it is placed in the desired position with sufficient quantity, unlike discrete fibers that are randomly dispersed and oriented thus it is low efficient. **Swamy** and **Mangat** (1974) stated that the random orientation of the fibers causes non-sufficient utilization whence control of cracking, strengthening or stiffening. Moreover, **Sri Ravindrarajah** and **Tam** (1984) reported that for beams, there is no considerable effect of the existence of fibers in the compression zone. The combination between the Glass Fiber Reinforced concrete (GFRC) and ordinary steel-reinforced concrete advantages leads to the textile reinforced concrete (TRC) (**Hegger** and **Voss**, 2008). **Peled** and **Mobasher** (2005) stated the superior tensile behavior of AR glass fabric composites in term strength and toughness as compared with the conventional Glass Fiber Reinforced concrete (GFRC). Generally, more than 3% of chopped fiber volume fractions is required to reinforce concrete products effectively **Mobasher** (2011). Thus TRC will reduce the cost of structures compared with FRC by means of reducing the volume fraction of fibers that required (**Cuypers** and **Wastiels**, 2006). Figure (1-3) shows the combination between the steel reinforced concrete and fiber reinforced concrete effects to form the textile reinforced concrete.

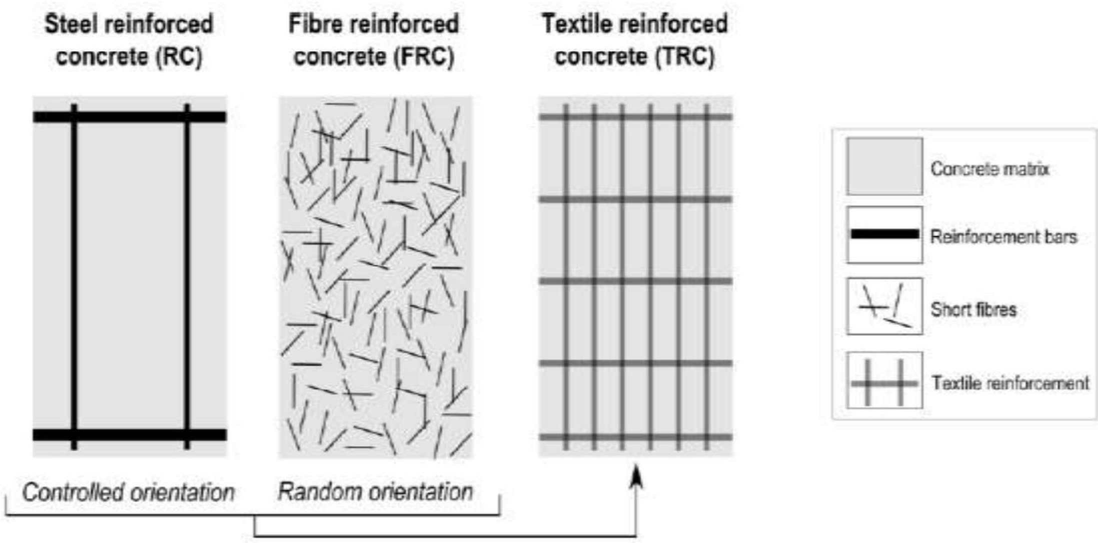


Figure (1-3): Combined effects of RC and FRC forming TRC (Hegger et al. 2006)

1.3 TRC Applications

Textile reinforcement is an advantageous material since it is offering corrosion resistance which considered an essential factor in term of long performance. Thus, it can produce thin walled concrete elements with 10 mm cover thickness (**Hegger et al. 2006a**). Moreover, it gains the possibility to control the orientation reinforcement, density and the yarn distance in addition to the flexibility and imposition of textile reinforcement.

1.3.1 Facade Panel

Precast concrete Facade elements have been used since the end of 1950s. Conventional steel reinforced concrete (RC) elements command the precast market for overlaying concrete buildings. RC elements differentiate by high thickness because of the thick cover of concrete that is necessary to avoid steel reinforcement corrosion, this is considered a disadvantage that reduces RC efficiency. Over the last two decades, new materials are used to assist extremely reduce the thickness and weight of precast Facade elements. Textile reinforced concrete (TRC) is one of these materials. Figure (1-4) shows TRC Facade panels.

Figure (1-4): Different buildings with TRC facade panels

1.3.2 Foot Bridges

(Albstadt-Lautlingen) was the longest textile-concrete bridge around the world to date with almost 100 m length. The bridge consists of six pre-cast parts were finished in (Wochner GMBH) pre-cast plant with maximum length of (17.2) m. These parts were reinforced by alkali-resistant glass reinforcement in combination with a conventional steel pre stressing. The combination of glass reinforcement and pre load allows for extremely slim bridge construction with a height of only 43.5 cm. That in the railing and under the steel columns integrated lighting system emphasizes the lightness of the concrete superstructure. A special feature is that the bridge is completely executed without any surface protection system. Even if it should come to unscheduled cracking and deicing salts in the construction would penetrate, this would be harmless to the bridge, because the reinforcement is not corroded. With regard to today's corrosion problem in bridge construction, this is one future-oriented construction. Figure (1-5) shows the (Albstadt-Lautlingen) footbridge in Germany which was completed in 2010.

Figure (1-5): (Albstadt-Lautlingen) footbridge (https://structurae.net/photos //201135-fussgangerbrucke-lautlingen)

1.4 Statement of the Problem

The steel corrosion issue requires thick concrete cover which leads to increase the dead weight of structural member. On the other hand, the concrete cover thickness, perfectly affects the flexural behavior of the memb

-er since the thickness is deducted from the effective depth. The reinforcing materials such as textiles with excellent mechanical properties are used to reinforce concrete with the minimum area of steel reinforcement or instead of the steel mainly to overcome the corrosion issue, reduce the member thickness, reduce the self weight and improve the ductility.

1.5 Aim and objectives of the study

Investigating the flexural behavior of the textile reinforced one-way slab mortar considered the main aim of this study. Moreover, it aims at comparing the experimental results with some analytical methods from the previous studies. The specific objectives that are accounted in this study are:

1- Investigating the effects of the several parameters on the flexural behavior of the textile reinforced one-way slab mortar, like:

- Number of textile layers,
- Removing of the cross weft yarns, which achieved by the gradual removing of the weft yarns from the reinforcement mesh by removing one weft yarn for one warp yarn, which represents the (50%) percent, two weft yarns for one warp represent (66.67%) and three weft yarns for one warp is the (75%).
- And, adding different chopped carbon fiber percentages,

2- Studying the effects of combination between the textile reinforcement and the steel reinforcement on the flexural behavior of the steel reinforced one-way slab mortar.

3- Studying the cracking behavior (crack width, first crack and crack spacing).

4- Investigating the bond behavior between the textile reinforcement and mortar.

5- Comparing between the experimental results of steel reinforced mortar (SRM), textile reinforced mortar (TRM) and fiber reinforced mortar (FRM) one-way slabs.

1.6 Methodology and Limitation of the study

The experimental program of this study consists of casting, testing of twelve one-way slabs. The obtained results discussed in terms of ultimate load, load-deflection relationship, tensile strain of the steel, mortar compressive strain, moment curvature relation, tension stiffening, crack pattern and mode of failure. The limitations related to the aspects are summarized as follows:

- The long term performance (Durability) is not carried out in this study.
- The effect of curing conditions on the bond between the textile reinforcement and the mortar is not investigated in this study.
- The effect of rate of loading on the flexural behavior of the textile reinforced mortar slabs is not investigated in this study.

1.7 Layout of the study

- Chapter one is a general introduction to Textile reinforced mortar (TRM) and the possibility of using the textiles as a main reinforcement in the structural applications instead of other types of reinforcement. It also describes the aims of the study.
- Chapter Two presents the literature review of the previous work concerning TRC applications.
- Chapter three explains the experimental program and the properties of the materials used. It contains details of the tested (TRM, SRM and FRM) slabs, mortar mix and test set up are also described.
- Chapter four presents the experimental results of the whole tests that took place in this study and their discussion with details.
- Chapter five represents the conclusions obtained from this study and recommendations for future studies.