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RECENT DEVELOPMENTS ON FLEXURAL BEHAVIOR OF GREEN CONCRETE MADE FROM DEMOLISHING WASTE

Ghulam Shabir Bhatti*[1], Bashir Ahmed Memon[2], Mahboob Oad[3], Muhammad Aachar Zardari[4] and Amjad Hussain Bhutto[5]

[1]Ph.D Scholar Civil Engineering Department QUEST Nawabshah, Pakistan.
[2]Professor Civil Engineering Department QUEST Nawabshah, Pakistan.
[3,4,5]Assistant Professor Civil Engineering Department QUEST Nawabshah, Pakistan.

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***Corresponding Author**
Ghulam Shabir Bhatti
Ph.D Scholar Civil Engineering Department QUEST Nawabshah, Pakistan.

ABSTRACT

The use of indigenous and ecofriendly materials in development of concrete is active area of research to save the environment from negative impacts of primary processes of conventional ingredients of concrete. The use of such materials will lead towards the economy of the project if treated at industrial level. In this research article recent developments regarding the flexural behavior of concrete using recycled aggregates from demolished concrete are presented. The review is concentrated on deflection, flexural strength, cracking, long-term effects, and fire resistance. Different replacement levels of conventional coarse aggregates with recycled aggregates from demolishing waste are used in development of green concrete. Results of various research attempts are analyzed. It is evident that despite of good quantum of work on the topic the scatter in results is there.

KEYWORDS: Green Concrete, alternative aggregates, demolishing waste, recyclable aggregates, plain concrete, flexural behavior.

1. INTRODUCTION

Concrete is most widely used material in construction industry. Even it is believed that it is extensively consumed material after water. But several environmental issues are also associated with the ingredients of concrete, i.e. CO_2 emission due to manufacture of cement and quarrying of aggregates. Thus, search of alternative ingredients of concrete remained active area of research among the scholars. Since past few decades the green concrete has got wide acceptance among researchers and industry personals. It is the concrete made by using waste materials as full or partial replacement of one or other conventional ingredient of concrete. It is also called eco-friendly or eco-concrete. Also, it does not require any modification of concrete making process. Mainly three advantages; decreased use of conventional material, reduction in CO_2 emission and reuse of the materials; are attributed to the green concrete. Application of green concrete has been attempted in buildings, roads and bridges. However, few disadvantages i.e. higher water absorption, varying compressive strength, higher shrinkage and creep and less life, are also associated with it.

Various waste products as cement, fine and coarse aggregates or as an additive are attempted by different scholars around the globe to develop green concrete. Among them bricks, glass, industrial waste, agricultural waste, by products, domestic waste etc. are few. Study of the basic, fresh and hardened properties of resulting concrete shows varying degree of acceptance. Among the materials used for the purpose, the quantum of construction and demolishing waste is comparatively more than others. It is particularly true in urban area where migration of peoples from different corners of the country require more living and associated space. On the contrary, in urban areas space problem is a hurdle for new development. Therefore, the industry is forced to opt vertical expansion in place of horizontal development. Generally, it is done by demolishing old or deteriorated structures. The phenomenon leads to the generation of huge quantum of the demolishing waste. This waste generally goes to landfills. But with time consumption made the areas unavailable. This require transportation of the waste to far distances, leave it unattained or dumping it in or near the useful lands. None of the option is feasible, particularly in country like Pakistan where most of the land nearby cities is agricultural land. Thus, dumping the waste in or near by such areas will not only destroy the land but adversely affect the economy of the country due to reduction of the agriculture.

A way of dealing such waste is its reuse in the new construction. A good quantum of the waste is used in floors, plinth protection and leveling but even then, the residual amount of the waste is large and require proper treatment. As coarse aggregates used in the fresh concrete is in greater quantity than other ingredients therefore, the use of the waste as coarse aggregates in fresh concrete will result in potential reduction in waste management. It is evident from literature that the topic has been remained active among researchers since past few decades. Various aspects of the concrete have been studied but the scatter in the obtained results is probably the main hurdle in generalization of the standards regarding the concrete.

Therefore, this paper presents the review on green concrete with reference to flexural behavior of the concrete made by using partial replacement of conventional coarse aggregates with coarse aggregates from demolishing waste.

2. LITERATURE REVIEW

To develop green concrete use of waste materials or byproducts of the primary processes has remained active area of research among scholar. Different review articles.[1-6] on production and use of green concrete and alternatives of cement are reported in literature. Memon,[7] in his review paper addressed the recent development on the use of green concrete with particular reference to processing of aggregates. These review papers show wide scatter in the results of different parameter of the green concrete.

Different waste materials as secondary ingredients or as supplementary materials have been attempted. For example waste bricks,[8] jute,[9] glass,[10,11] ceramics,[12] fiber composite,[13] plastic,[14,15] steel fiber,[16] foundry sand,[17] quarry dust,[18] polymer,[19] agricultural waste,[19,23] e-waste,[24] industrial waste,[25-27] coir,[28,30] granite,[29] coal waste,[30] slag,[31] rubber,[32] and construction and demolishing waste,[7] are few examples in long list of the materials.

Various components of demolishing waste i.e. glass, bricks etc. have been attempted by different scholars in fresh concrete but the major portion of demolishing waste is the concrete. Therefore, it is used in fresh concrete as full or partial replacement of the coarse aggregates.[33] However, few problems; i.e. processing in required size, old mortar attached with aggregates, life of structure / aggregates; with these aggregates are also reported.[7] Processing of aggregates may be done in usual fashion by transporting the waste to the crushing plant. But leads to additional cost of the transportation. Therefore, government policies and incentives are required to regularize the matter.[35] Normally jaw, impact and cone crushing35 are used to produce coarse aggregates.[35] However different alternative techniques.[36] to improve the performance of the aggregates is also reported in the literature including double crushing and air jigging process.[37] Also, removal of porous particles and cement mortar attached to the aggregates is attempted by using mineral processing.[38] but the study focused on the use of the waste as fine aggregates.

Old mortar attached with aggregates increases the water absorption rate giving rise to higher water demand of the resulting mix. The parameter is even reported up to 3.8 times than that of conventional concrete. This higher water absorption should be addressed in concrete mix design, otherwise, the workability of the concrete will become a problem.[33 Similarly, age of structure and old mortar together affects the specific gravity of the aggregates. The parameter is less in comparison to that of conventional aggregates35 However, the difference is within 20% range.[34]

Strength of concrete is one of the key parameters in quality evaluation. Thus, the same should be evaluated for the green concrete also, to this end effect on compressive strength.[34] due to use of demolishing waste as partial replacement of conventional aggregates is studied by Oad and Memon. From the laboratory investigation the authors concluded 50% dosage of demolishing waste as optimum as at this level of replacement the reduction in compressive strength was observed equal to 26%. Jain et al,[39] reported 11% reduction in compressive strength at 100% replacement level of conventional coarse aggregates with recycled coarse aggregates. Adnan et al,[40] reported 23.7% reduction in the same parameter for 50% replacement level where as Topcu and Senge,[41] reported 11% reduction in compressive strength at 50% dosage of recycled aggregates. The above mentioned are few examples among long list for the study of the parameter, but the variation in the results is evident.

For quality control of the concrete, standard procedures and standard size specimens are used. But it is observed commonly that different size specimens are used for preparation of samples. This deviation in size affects the strength. Therefore, two different studies present laboratory investigations to check the effect of cylinder size,[42] and cube sizes,[43] on compressive strength of green concrete made by using demolishing waste as coarse aggregates. Both studies developed correction coefficients to map the compressive strength of non-standard size specimens with standard size specimens.

Proper curing is a key factor for good strength of concrete, however water used should be the potable water. Variation in quality of curing water may lead to the improper strength of the concrete therefore, effect of curing type on compressive strength and tensile strength has been separately studied by Ali et al,[44] and Memon et al.[45] From the laboratory investigations of five different methods of curing the authors observed that curing by gunny bags results in increased strength than conventional method of curing. They observed 1.67% and 0.3% increase in compressive and tensile strength respectively.

Among supplementary cementous materials fly ash is one and has got wide acceptance of researches around the globe. It has been used in concrete with calcium chloride and alkaline solutions,[46] polymer and marble powder,[47] high volume above 60%.[48] In another research study by Yu et al,[49] tested green concrete prepared by using fly ash and heat curing. Based on the test results of 1-, 3- and 7-day compressive strength the authors developed guidelines for concrete incorporating fly ash to augment the recommendations of IS 456:2000. High volume fly ash from china and India has also been used by Yu et al,[50] to cast and heat cure the specimens. Use of high volume allowed them to reduce the water-binder ratio to 0.3. The test results showed the authors encouraging behavior of the fly ash in new concrete. Chandio et al,[51] on other hand used fly ash and recycled aggregates from demolishing waste to develop green concrete. The research aimed to investigate the effect of two waste materials on the compressive strength of green concrete. From the test results of cylindrical-specimens, authors observed that 5% fly ash in combination with 50% recycled aggregates as replacement of cement and conventional coarse aggregates respectively gives comparable results of compressive strength. Fly ash in combination of silica-fume and blast furnace slag has also been studied for consistency, strength and cost.[52] Observation from test results was that fineness of silica-fume increases the consistency of the mix. Increase in strength was recorded with fly ash from 5% - 15%. Also, the authors observed 20% reduction in overall cost of the proposed mix in comparison to conventional concrete.

Green concrete has been studied for different factors such as combination of stone dust, marble sludge and fiber reinforcement for compressive vs flexural strength,[53] recycled products from UAE,[54] RCA and FRP sludge,[55] shrinkage of concrete panels made by using demolishing waste as coarse aggregates,[56] effect of aggregate size,[57] effect of blending ratio,[58] porosity,[59] effect of cement content.[60] Also, the research studies has been carried out to develop optimum design criteria for green concrete overlays,[61] use of green concrete in transportation project,[62] strength evaluation of self-compacting concrete,[63] effect of impact loading,[64] and bond performance,[65] Although good deal of word is devoted to study the green concrete yet the scatter in result is observed. This shows that still more work in the subject area is required to build the confidence of the scholars and industry stack holder.

3. Flexural behavior of green concrete

The capacity of structural members to resist bending action is termed as flexural strength. It is controlling parameter in design of most of structural members. Therefore, it needs to be understood well particularly for green concrete. In a review article about flexural performance of reinforced recycled concrete beams, Gagan and Agam,[66] argues that about 8 to 12 million tons of conventional aggregates are consumed per year. Quarrying of such quantum of aggregates poses serious environmental issues. Thus, alternative aggregates such as from demolishing waste has wide scope to save environment and conserved natural sources of aggregates. The authors reviewed impact of RCA on the flexural behavior of RC beams. From the review of state of art authors observed that reinforced concrete RCA beams observes more deflection at mid-span than that of conventional RC beams. Also, they observed that flexural strength of the beams is less than conventional RC beams. However, addition of some fibers in the green concrete improves all its properties including deflection and flexural strength. In another attempt Sato et al,[67] used recycled concrete both as fine and coarse aggregates to study various short- and long-term properties. From the laboratory investigations the authors observed reduction in cube crushing strength, modulus of elasticity and increase in deflection, creep and shrinkage for concrete of strength 21 MPa. They also observed no difference in ductility factors of conventional, recycled coarse and recycled fine aggregates in the concrete. Hence concluded possibility of its use in structures depending upon proper design and proper limit of application.

3.1 Deflection

It is one of the key indicators of the quality and durability of concrete. Maximum deflection in concrete beams should be with in allowable limits of the code. The parameter has been studied by different scholars around the globe for recycled aggregate concrete. Sindy et al,[68] based on the results of 28-cured reinforced recycled aggregate concrete beams cast using 0.5 and 0.65 water-cement ratio observed good correlation between deflection and bending moment. The authors used 20%, 50% and 100% replacement of conventional coarse aggregates with coarse aggregates from demolishing waste. The authors also observed that ratio of experimental and calculated deflection for both types of concrete is same. Therefore, argue that design code used for conventional concrete can be used without any alteration for recycled aggregate concrete.

From the literature it is generally observed that the deflection of recycled aggregate concrete beams is higher than the conventional concrete beams. Deflection results obtained by different scholars are summarized in Figure 1. It may be observed that except reference number 86 and 101 (Both references report same increase in deflection) wide scatter in the results is present.

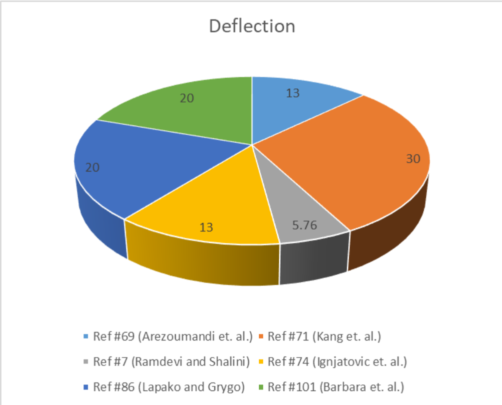

Figure 1: Deflection.

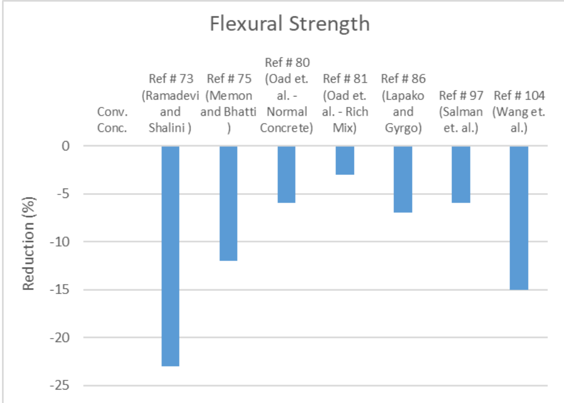

Figure 2: Flexural Strength.

3.2 Flexural Strength

The property of concrete is an important one to resist the bending stresses. It is well understood for conventional concrete. However, in recycled aggregate concrete, use of recycled aggregates affects this property resulting in reduced flexural strength of the members. Attempts to understand and improve the property remained active area of research among scholars. Arezoumandi et al,[69] based on the laboratory experiments on eight full scale beams concluded that the flexural strength of the recycled aggregate concrete is comparable with that of the conventional concrete. Fathifazl et al,[70] also addressed the issue through their research program. The authors used new method of proportioning the mix with RCA. They used relative amount of mortar and aggregates separately and prepared beams. They found flexural strength of beams comparable with conventional concrete. In separate attempts by Ignjatovic et al and Lapako and Grygo,[71] observed no significant different in flexural strength of recycled aggregate concrete and conventional concrete. Figure 2 shows the flexural strength results obtained by different scholars for recycled aggregate concrete. Additionally, Evangelista and de-Brito,[72] in their research program observed reduced flexural strength of the RCA. They also argued that although some countries prepared and adopted regulations for use of the waste but still the practice is rare. Therefore, emphasis on preparation and adoption of the regulations. Knaack and Kurama,[76] based on laboratory investigations for nonlinear behavior and failure concluded very small effect on shear and flexural capacity. Chaboki et al,[77] on other hand reported increased shape and reduced flexural strength of beams cast with all-recycled aggregates. Whereas comparable flexural performance of recycled aggregate beams was concluded by Choi et al.[78] The property was also studied by Oad et al.[93] by testing 72 reinforced recycled aggregate beams with water-cement ratio from 0.54 to 0.7. The authors observed fluctuating behavior of flexural strength with increase in water-cement ratio. At highest water-cement ratio used, authors observed 24.46% reduction in flexural strength in comparison to that of conventional concrete.

Use of additives in concrete to improve its strength particularly flexural strength is also an active aspect of research. Rice husk ash is one among them. This waste is used by Naveen et. al. to study its effect on M30 and M60 concrete. From the analysis of experimental observations, they observed that the use of the product improves flexural strength 8.88 and 6.05 times than the flexural strength of conventional concrete. Cook.[95] suggest replacement of ordinary cement with calcium sulfoaluminate cement to improve the flexural strength than conventional concrete. The author from his experimental program also concluded that same code equations can be used for mix design with proposed type of cement. Fibers in concrete generally improves its performance. Considering this Salman et. al. used steel fibers in recycled aggregate concrete for beams cast with 100% recycled aggregates. From the laboratory investigations they concluded about 39% increase in flexural capacity.

He et al,[102] used crumb rubber as additive in recycled aggregate concrete to study its effect on flexural strength. From the test results of 18 prisms authors observed comparable flexural strength with conventional concrete. Flexural fatigue performance of recycled aggregate concrete beams with all recycled aggregates was studied by Arora and Singh.[103] The experimental program showed the authors high variability of the life with recycled aggregates than conventional concrete. Flexural strength with respect to seismic effect is addressed by Wang et. Al.[99] Experimental results showed the authors that dosage of recycled aggregates has less effect on seismic properties. They also concluded that the fiber-based model gives comparable flexural resistance of the beams.

3.3 Long Term Effects

Long term effects of loading i.e., shrinkage, creep, crack propagation etc. sometimes result in major loss of the structural members. Therefore, should be understood for recycled aggregate concrete before putting it in practice. In the following literature is reviewed for these effects.

3.3.1 Shrinkage

Drying shrinkage is another long-term effect of concrete which increase with time. Sato et al[67] observed 2.5- and 1.3-times shrinkage after one-year in recycled aggregate concrete with and coarse and fine aggregates respectively. Tam et al[87] in their research program used 30% and 100% replacement of conventional aggregates with different water-cement and aggregate-cement ratios. They observed increase in shrinkage but with different behavior. They also found that water-cement and aggregate-cement ratios are inconclusive for shrinkage. Domnigo et al[88] also studied shrinkage but using constant water-cement ratio and found 70% increase in drying shrinkage after 180 days. Wang et al[104] while studying medium strength concrete containing 100% recycled aggregates observed 24% increase in drying shrinkage.

3.3.2 Creep

Under sustained loading another long-term effect of concrete is creep which can cause damage to it. To this end Sato. et al[67] observed higher creep in recycled aggregate concrete. But improvement was recorded by the authors when they recycled fine aggregates were used in the concrete. After 180 days creep of the beams cast with 20%, 50% and 100% replacement of natural aggregates with constant water-cement ratio was observed by Domnigo et. al[88] is equal to 51%. With different reinforcement ratio beams will behave differently towards short- and long-term effects. Considering this phenomenon Ye et al[96] studied different strength concrete beams and found that reinforcement percentage do not have significant effect on creep of the beams if concrete is of middle strength but becomes prominent if high strength concrete is used.

3.3.3 Crack pattern, Spacing and Width

Crack spacing is another parameter of long-term effects. Crack spacing observed[67] for normal recycled aggregate concrete is in the range of 0.92 to 1.37 times that of conventional concrete. Whereas the same for recycled aggregate concrete with recycled fine aggregates is 0.74 to 1.26 times that of conventional concrete. Width of the largest crack for above mentioned two types of concrete was observed in the range of 0.57 – 1.3 and 1.1 – 1.7, respectively. Authors in[68] observed different cracking pattern between conventional and recycled aggregate concrete. Also, they observed that cracking moment decreases with increase in the dose of recycled aggregates. While observing the crack pattern they observed similar behavior of both types of concrete. The similar conclusion for the aspect was recorded by Kang et al[71] The crack spacing in recycled aggregate concrete was lesser than conventional concrete beams. However, few horizontal cracks at tensile reinforcement zone in recycled aggregate concrete was recorded due to higher strain and lesser bond strength. Ignjatović et al[74] recorded first crack occurrence at 10% lower load than conventional concrete. Khatib et al[98] attempted glass waste as fine aggregate in recycled aggregate concrete containing demolishing waste as coarse aggregates and found significant improvement in ductility, crack load and crack spacing.

3.3.4 Long term deflection

Under sustained loading deflection increases with time. Long term deflection up to 380 days was studied by Choi and Yun[79] for beams cast with 50% and 100% dose of recycled aggregates. From the obtained results authors observed that deflection due to creep and shrinkage is comparable with one specified by ACI. They also developed numerical equation to predict the long-term deflection for recycled aggregate concrete beams. Manzi et. al.[82] used demolishing waste as fine aggregates to study the long-term defection and other parameters of the beams. Base on the results authors argued that high strength and low long-term deflection may be obtained by tunning the grain size distribution and specific gravity of aggregates. In separate studies by Oad et. al. the authors investigated long-term deflection, stain and crack width for six,[83] nine84 and twelve85 months. From the obtained results of sustained loading authors observed almost similar P-Δ effect in comparison to conventional concrete beams. The results of other parameters of the study are tabulated in Table 1.

Table 1: Long-term parameters of reinforced concrete beams.

#	Reference No.	Load sustained for (months)	% change with respect to conventional concrete		Crack width (mm)
			Deflection (mm)	Strain	
1	# 83	6	22.1	20.4	0.50
2	#84	9	6.24	6.32	0.52
3	#85	12	4.96	5.64	0.81

3.5 Fire Resistance

Fire is one among many other hazards which a structure some time is exposed. Fire not only destroys the appearance of the structure but also degrades its strength. Good quantum of work to the extent of enough confidence is done. Good many research papers are also published by different scholars regarding the effect of fire on recycled aggregate concrete. Mechanical properties of recycled aggregate concrete (20%, 50% and 100% replacement of conventional aggregates) exposed to 400°C, 600°C and 800°C for 1 hour are studied by Vieira et al,[100] The authors form analysis of laboratory testing observed that there was no difference in thermal response and post fire mechanical properties. The duration of fire used in this study is just one hour, but the elongated and elevated temperature cause deterioration in various properties of the concrete as reported by Buller et. al. in four different studies in which reinforced recycled aggregate beams were exposed to fire for 6 hours,[89] 12 hours,[90] 18 hours[91] and 24 hours[92] Their findings along with finding of few other scholars among many others are summarized in Table 2 and Table 3.

Concrete exposed to elevated temperature up to 600°C had minor hairline cracks. The phenomenon was observed by Salau et al,[109] thus they concluded good performance of it at elevated temperatures. The performance of concrete column containing recycled aggregates was observed better than that of conventional concrete when exposed to fire.[110]

Table 2: Deflection and flexural strength of recycled aggregate concrete exposed to fire.

S. No.	Reference No.	RCA (%)	Mix	Water-Cement Ratio	Fire duration (Hr)	Temperature (°C)	Deflection (mm)	% change with respect to conventional concrete
1	89	50	1:1.5:3	0.54	6	1000	6.03	-8.24
2	90	50	1:2:4	0.54	12	1000	7.05	-48.0
3	90	50	1:1.5:3	0.54	12	1000	8.40	-38.51
4	91	50	1:2:4	0.54	18	1000	17.61	-19.06
5	91	50	1:1.5:3	0.54	18	1000	9.48	-21.82
6	92	50	1:2:4	0.54	24	1000	10.62	-23.57
7	92	50	1:1.5:3	0.54	24	1000	11.60	-32.41

Table 3: Compressive strength of recycled aggregate concrete exposed to fire.

S. No.	Reference No.	RCA (%)	Mix	Water-Cement Ratio	Fire duration (Hr)	Temperature (°C)	% change with respect to conventional concrete
1	105	100	1:2:4	0.5	2	900	-37.73
2	106	75	1:2:4	0.4	4	500	-28
3	107	50	1:2:4	0.5	2	800	-15
4	107	100	1:2:4	0.5	2	800	-50
5	108	50	1:2:4	0.27	2	800	-17.08
6	108	50	1:2:4	0.36	2	800	-16.76

3.6 Failure Mode

Failure mode of structural members is one of the important parameters to ensure serviceability of the structures. The aspect for recycled aggregate concrete is studied by several scholars around the globe. Table 4 below shows the conclusion of few studies regarding the failure mode among many others.

Table 4: Failure mode of recycled aggregate concrete.

S. No.	Reference No.	Exposure	Failure mode
1	67	Short term loading	Flexure-shear, flexure
2	68	Short term loading	Flexure-flexure
3	70	Short term loading	Flexure
4	74	Short term loading	Flexure
5	75	Short term loading	Flexure
6	83	6 month sustained loading	Flexure
7	84	9 month sustained loading	Shear
8	85	12 month sustained loading	Flexure
9	89	6-hour fire at 1000°C	Shear
10	90	12-hour fire at 1000°C	Shear
11	91	18-hour fire at 1000°C	Shear
12	92	24-hour fire at 1000°C	Shear
13	102	Short term loading	Flexure

4. CONCLUSION

This article reviews the recent developments on use of demolishing waste as recycled aggregates in concrete with reference to flexural behavior. It is observed that several successful attempts are available in literature regarding the use of the material. However, for certain conditions results are very comparable even better than conventional concrete but in most of other cases the scatter in results of same parameter of study is there. Rules and regulations regarding the recycling and use of the demolishing waste is present in many countries. But their implementation is rare in many places. Therefore, it is concluded that in addition to the implementation of rules and regulation, still more work is required to develop the confidence level.

5. Declarations

5.1. Conflict of Interest

Authors declare no conflict of any type of interest at any level of the research.

5.2. Funding Statement

The project is part of Ph.D research, no any funding is received from any sources for research presented in the article.

5.3. Authors Contribution

Ghulam Shabir Bhatti: collected dada and prepared draft.

Bashir Ahmed Memon: Supervision, Dada analysis, methodology. further read and prepared original draft.

Muhammad Aachar Zardari: Reviewed and edited original draft**.**

Mahboob Oad: Review, re write, analyzed and prepared original draft for publication
Amjad Hussain Bhutto: helped in collecting data and material.

5.4. Availability of Data and Material

All the data is available with first author. The paper being review paper do not involve any material.

5.5. Compliance With Ethical Standards

Ethical standards are followed during the research presented in accordance with policy of journal.

5.6. Consent to Participate

Authors are ready to participate in discussion etc. related to the research.

5.7 Consent for Publication

The authors authorize the journal editor with all consent to publish the research as property of journal.

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