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Use of powdered and liquid polymers including pre- packaged Polymer Modified Mortar in Concrete technology in Pakistan: Types Being Used, Application Areas, Market Size, Cost Trends and Future Prospects

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ABSTRACT

Purpose: This study sees into the adoption of polymer modified concrete in Pakistan through evaluating types of polymers used, applications of polymer concrete, coverage in the market, changes in the cost of polymer concrete and future prospects, construction industry. While the incorporation of polymer is well known around the world for its beneficial effect on performance and durability of concrete, there is little globally available industry level evidence for the development of construction markets like that of Pakistan. The purpose of the study is to make a comprehensive technical and market oriented survey on the aspects of utilization of polymer in Pakistan.

Design/Methodology/Approach: A structured questionnaire survey was carried out amongst these participants which comprised of 367 construction professionals such as engineers, contractors, consultants and material suppliers. Responses were formatted through a Likert scale methodology and were analyzed through descriptive statistical methods to assess usage trends, performance perceptions and market barriers.

Findings: Results show that 68% of the respondents do regular use of superplasticizer-based polymer with polycarboxylate ether (PCE) being the dominant type with mean score passage >3.8/5. Some 61% of professionals were have associated the use of polymers with the improvement of workability; 54% with the improved development of strength. Durability advantages of lower permeability and longer service life were accepted by more than three quarters of the participants. Polymer latexes and fibers thus have been more frequently used in the repair and waterproofing works than in the mass concrete.

However, 72% of the respondents mentioned high cost and 65% of them reported import dependency as major barriers that limit wider adoption. Trends in the market have been slow and gradual growth due to high rise projects, infrastructure projects

Implications/Originality/Value: The study provides one of first industry-wide empirical assessment of polymer used in concrete in Pakistan through technical performance perceptions along with market realities in Pakistan. Findings include the need for local manufacturing, industry training and supportive policy frameworks for better adoption. The results offer an evidence-based advice to engineers, material producers, researcher as well as policymakers who wish to promote durable and performance-oriented concreting models in emerging construction markets.

Keywords: Polymer-modified concrete; Superplasticizers; Concrete durability; Polymer admixtures; Construction materials; Market adoption; Sustainable construction; Pakistan construction industry.

1 Introduction

Concrete is the most used construction material in the world because of its versatility, accessibility and structural ability. However, conventional concrete is still facing difficulties on workability control, durability under aggressive environmental exposure, permeability and long term service life (Batool et al., 2024). To overcome these limitations, the addition of polymers in the concrete technology has attracted much attention during the last decades. Polymer-based admixtures such as superplasticizer, latexes, and polymer fibers alter the microstructure of cementitious systems, increase the particle dispersion, increase the bonding properties, and decrease the water requirement, thus leading to an improvement in the fresh and hardened concrete properties (Debbarma et al., 2024). Numerous studies have shown that polymer modification brings improvement of strength performance, lower permeability, better resistance to chemical attack, and longer service life time leading to polymer modified concrete (PMC) to be an important part of modern durability-oriented design practices (Mehmood et al., 2021).

Globally PMC has been applied more and more in the fields of high-performance buildings, repair and rehabilitation works, industrial flooring, overlays and waterproofing systems as well. Despite these advancements, there is a lot of variation in the extent of polymer adoption by country and region; in particular in developing construction markets where technical awareness, price sensitivity and supply chain limitations play a role in making the material selection decisions (Taheri, 2013). Pakistan's construction industry is witnessing high growth due to urbanization, construction of infrastructure, high-rise development, leading to a huge demand for high-performance and durable construction materials. Although polymer admixtures are offered in the local market, there is still limited information on systematic documentation of the industry-wide use, application trends and market behaviour (Alhawat et al., 2024).

The general research challenge can be narrowed down to the disconnect between the proven technical benefits of the polymer-modified concrete and limited knowledge about how these materials are actually used in the Pakistani construction industry (Molla et al., 2024). Existing research mainly concerns laboratory studies of material performance, whereas empirical studies on pattern of adoption in the industry, market trends, and cost associated barriers are limited. As a result, there is a lack of proper evidence on the advancement of material science and its implementation in Pakistan's construction practices (Zahid et al., 2024).

This research considers this gap and therefore aims to cover the evaluation of polymer application in the concrete technology field in Pakistan from a comprehensive point of view (Al Rashid et al., 2021). The objectives include identification of various types of polymers currently in use, analysis of areas of application, analysis of market penetration and cost trends, and consider the prospects for future adoption of polymers in the construction sector. The research combines technical performance perceptions with industry and market with an extensive survey of construction professionals (Zaid et al., 2024).

The research is important because it provides a connection between material engineering research and construction industry practices (Ali et al., 2024). Quantifying the professional perceptions and market-related limitations at a national scale, the study forms one of the first integrated and technical market orientations for polymer-modified concrete in Pakistan. The findings are expected to inform the policy makers, researchers, and industry stakeholders in promoting high-performing, durable, and sustainable concrete in the new construction market (Emmanuel et al., 2025).

2 Literature Review

2.1 Introduction to the Use of Polymers in Concrete Technology

The introduction of polymers when added in cementitious materials are a huge step in the technology of concrete to overcome the limitations of direct mixes (Tariq et al., 2025). Early developments in polymer modified concrete (PMC) were on improving the binding properties and reduction of permeability mainly for repair and overlay applications (Elmousalami et al., 2025). Over time, advances in polymer chemistry and in the development of admixture technology have made it possible to have wider ranges in applications to structural concrete, high performance concrete mixes and larger applications in durability-focused design (Wang et al., 2021). Contemporary research brings out that the hydration environment and microstructure are modified with the addition of polymers, the interfacial transition zone (ITZ) properties are improved and the better stress distribution within the matrix of cement is contributed. These mechanisms are the basis of the enhanced mechanical and durability properties that are associated with PMC (Hasan et al., 2024).

In spite of the wide distribution of results of laboratory studies that demonstrate enhancement of performance, the levels of utilization of polymers vary all over the world (Rahmad et al., 2022). Developed construction markets are performance oriented and focus on life cycle durability and thereby a much larger use of PMC compared to the developing economies whose markets are often still cost driven and therefore, polymers are restricted to specialist applications (Junaid et al., 2022).

2.2 Classification of Polymers Used in Concrete Technology

Classification of polymers used in concrete technology can be formed based on the way they are incorporated and how they are used. The conventional classification is based on polymer additives in admixtures but recent trends in construction show that polymers are also widely used for repair, coating, flooring and composite binders. Hence, a dual classification is needed to capture both the material and application aspects (Ogunkunle et al., 2024). Admixture-based polymers are added to concrete or mortar to alter their characteristics. The most common polymers are superplasticizers based on polycarboxylate ethers (PCE), sulphonated naphthalene formaldehyde (SNF) and lignosulphonates. They enhance workability by cement dispersion via electrostatic and steric repulsion, and allow lower water-cement ratios. PCE polymers are the most effective in high-strength and high-performance concrete, but SNF and lignosulphonates are still used in more economical applications (Soni et al., 2022).

Latex polymers, such as styrene-butadiene rubber (SBR) and acrylic emulsions, are employed to improve adhesion, flexibility and durability. These are often used in repair mortars, overlays and waterproofing membranes because they function by forming a polymer film in the cement matrix. Polymer fibers, like polypropylene (PP), provide micro-reinforcement, enhancing crack resistance, toughness and durability. Their main aim is not to enhance compressive strength, but to mitigate shrinkage cracking and improve post-cracking properties. Polymers are extensively used in pre-packaged and applied systems, which play a vital role in construction durability, repair and protection (Khan, 2015).

Redispersible polymer powders (RDP) are incorporated into dry-mix mortars (e.g. tile adhesives, plasters) to enhance adhesion, flexibility and water resistance. Likewise, ready-to-use polymer-modified mortars are widely applied in repair and rehabilitation works for their quality and improved adhesion. Polymer-modified cementitious coatings are used for waterproofing and protection of surfaces, exhibiting crack-bridging and waterproofing properties. These are used in basements, water tanks and exposed concrete. Polymer resin systems, such as epoxy and polyester, are applied in high-performance applications, like flooring, crack injection and fast repair works. These systems are strong, chemical-resistant and have rapid cure times, but are limited by cost and sensitivity to application. Polyurethane (PU) systems are used as flexible coatings and waterproofing systems. Their flexibility and resistance to weathering make them ideal for roofs, expansion joints and exterior surfaces (Abbass et al., 2024).

The classification of polymers in concrete technology underlines their two-fold nature: mix-based polymers alter concrete properties, while application-based polymers improve durability, reparability and long-term performance. This holistic view is crucial when assessing the use of polymers in actual construction applications, especially in emerging markets where application-based solutions may prevail over mix-based modifications (Kalair et al., 2021). These categories are coherent with the polymer types that are based on applications, which are explored in the survey questionnaire, to maintain the consistency between the literature review and the empirical analysis.

2.3 Influence of Polymers on the Fresh Concrete Properties

Extensive researches establish that super plasticizer-based polymerase helps to drastically improve the workability by dispersion of the cement particles to lower the flocculation (Tan et al., 2023). The lower values of water-cement ratio are an indirect cause of an improvement of hardened properties. PCE polymers are particularly effective as they are minutely branched shape and they would provide electrostatic repulsion and steric steric hindrance for the polymer (Ahmed et al., 2023). Research studies have shown benefits in slump retention, bleeding and pumpability of polymer modified mixes. However, performance is a strong function of dosage, cement chemistry compatibility and environmental. Improper usage could lead to segregation or delayed setting which is why mix design practices need to be controlled (Qaidi et al., 2022).

2.4 Effects of Polymers on the Performance of Hardened Concrete

The hardened concrete properties of polymer incorporation are mainly depended on the microstructural modification. Reduced capillary porosity, improved ITZ bonding leads to improved compressive, tensile and flexural performance (Singh et al., 2025). Latex modified systems have more adhesion and toughness properties and therefore can be used for repair works (Yadav et al., 2022). Fiber-based polymers are involved in the control of the crack and impact resistance. However, increases in strength tend to be indirect, because of resulting decreases of water content, and not purely because of polymer chemistry.

Research indicates that a regular curing and inch mix design is needed for possible performance benefit (Patel et al., 2025).

2.5 Engagement of Durability Polymer modification

Durability improvement is those that are most widely-reported benefits of PMC. Polymer films formed in the cement matrix occlude pore channels in order to reduce permeability and also to save resistance to intrusion of chlorides, sulfate attack, and freeze-thaw (Abas et al., 2017). Latex modified systems have superior waterproofing properties and PCE-based systems have superior density and reduce the risk of shrinkage cracking. These properties make this especially applicable in aggressive environments and infrastructure applications where long term performance is important (Ilyas et al., 2024).

2.6 Embracing Industry and Market

While technical work on PMC covers a lot of ground, work addressing market adoption and industry practice is lacking, particularly in developing economies. Available literature suggests the polymer adoption in such regions in most cases are limited to high performance use or repair applications since of high material costs, importation and lack of technical awareness by small and medium contractors (Cavalli et al., 2023). In Pakistan the published research appear to be fairly focused on the laboratory studies of the performance of concrete with no empirical evaluation on the usage pattern in industry and/or working economy. As a result, there is lack of understanding of the role of professional perceptions, market forces and supply chain limitations in the decision making on the adoption of polymers (Rashid et al., 2025).

2.7 Identified Research Gaps

The review shows despite the technical benefits of polymers in concrete being well established, the need for improved integrated studies of material performance criteria in combination with an analysis of the market and industry adoption (Ding et al., 2024). Specifically:

- There is little empirical information on the type of polymers which predominate in industry.
- Application-specific trends of development of construction markets are understudied.
- Market size, cost barriers and growth potential, these are rarely sized up.
- The link between technical knowledge adoption and decision making is poorly documented.

Addressing these shortcomings requires industry-level studies which will make the connection between technical performance and economical and practical performance (Khalid et al., 2023). The present study provides a contribution to this field, in the form of a large-scale and professional evaluation of the use of polymers in Pakistan, making the link between the world of polymer science and the practice of construction (Lu et al., 2025).

3 Methodology

3.1 Research Design

This research used the quantitative and cross section approach, as a survey method, to study the use of polymer in concrete technology in Pakistan, construction industry. The research framework was designed in order to ensure the technical, practical, market-oriented aspects of polymer use due to standardization of the data collection and statistical evaluation (Dong et al., 2025). A survey approach was deemed most appropriate because the object of research is the practices in industry, the perceptions of professional, and economic constraints, practices and perceptions, for which cannot be suitably researched through laboratory experimentation alone. While such study is revealing as a source of information about how materials perform in experiment, to truly understand adoption, one needs to speak to practitioners that are involved in material selection, design, and implementation (Divyabharathi et al., 2024). The design chosen therefore opens a gap between the research in material sciences and the implementation of the construction industry. The questionnaire was structured to capture admixture-based and the application-based polymer system such as coatings, repair material, and products based on resin.

3.2 The Population and the Sampling Strategy

The study population was the professionals that actively involved in loss activities (involving concrete) all over Pakistan. Civil and structural engineers, contractors, construction managers, consultants, site supervisors and material suppliers for residential and commercial work for high-rise and infrastructure projects and repair/rehabilitation projects were included in the respondent group (Vigneshwaran et al., 2020). A purposive sampling technique was used to guarantee that the subjects had relevant technical knowledge and decision-making in the selection of concrete material used.

A total of 367 valid responses were obtained after being tested for responding for completeness and consistency. This sample size is statistically adequate for the studies of perception-based investigation of the construction industry and imparts adequate representation of different types of projects and professional positions. The variety of people surveyed enhanced the generality of the outcomes in the scope of the construction industry in Pakistan (Kazi, 2022; Khoo et al., 2021).

3.3 Developing the Survey Instrument

Data collection was done using a structured questionnaire that includes technical results and market aspects of polymer modified concrete. The instrument reflected several sections associated with the types of polymers that are utilized, fields of application, the perception of performance (workability, strength, durability), cost considerations, and barriers to adoption. Perception based variables were cultured on a 5-point Likert scale from 1 (strongly disagree) to 5 (strongly agree) (Aggarwal et al., 2021; Amare et al., 2023). This scaling method made it possible to quantify the subjective professional evaluations as well as a statistical comparison of the different variables (Abed et al., 2022).

The questionnaire design was based on established practice of survey research in order to ensure clarity, logical flow and technical relevance (Junaid et al., 2024). Questions were created to control ambiguity and prejudice. The structure of the instrument made it possible to collect data on both categorical and continuous type perception that was amenable to multivariate analysis.

3.4 Data Collection Procedure

The questionnaire was distributed through professional networks and using communication channels in the construction industry and contacting industry in an effort to get participation from practicing professionals. Respondents were told about the academic purpose of the research and participation was voluntary (Saravanan et al., 2023). Data collection process was conducted using a standardized procedure in order to ensure that the process remained consistent. Completed responses were reviewed to both check for missing data and internal inconsistencies before they are used in the data set for the purposes of ensuring reliability and accuracy of the results from the analysis (Sayem et al., 2020).

3.5 Data Analysis Techniques

Statistical analysis inside appropriate software program was conducted in order to transform the information reported in the survey directly into quantifiable information. Descriptive statistics, like frequency distributions, percentages and mean scores were used to establish dominant polymer types, trends in applications and prevailing perceptions in the industry. Comparative analysis of the mean values was helpful to establish the relative importance of performance characteristics such as workability enhancement, strength development and durability enhancement (Abdullah et al., 2024). Correlation analysis was applied for the analysis of the correlations between the perceived technical benefits and adoption trends. Where relevant, regression analysis was performed in order to try to explore the influence on patterns of polymer utilization of such variables as cost perception, technical awareness and the limitations of markets (Hasnain et al., 2025). These analytical tools were chosen because they provide both summary level understanding and evaluating the interdependencies of variables which will increase the explanatory power of the study.

3.6 Issues of Reliability and Validity

Measures were taken to ensure methodological rigor. The reliability of the survey was improved through the use of a structured questionnaire and standardized Likert scale responses. Screening of responses increased reliability of data and inclusion of various professional roles increased the content validity of responses as it is multiple perspectives in the construction value chain. The quantitative way makes possible the reproducibility and objective interpretation (Nwankwo et al., 2023).

3.7 Methodological Framework

The adopted methodology combines data structured collection and statistical analysis in order to provide a systematic and replicable evaluation of the polymer adoption in a developing construction market.

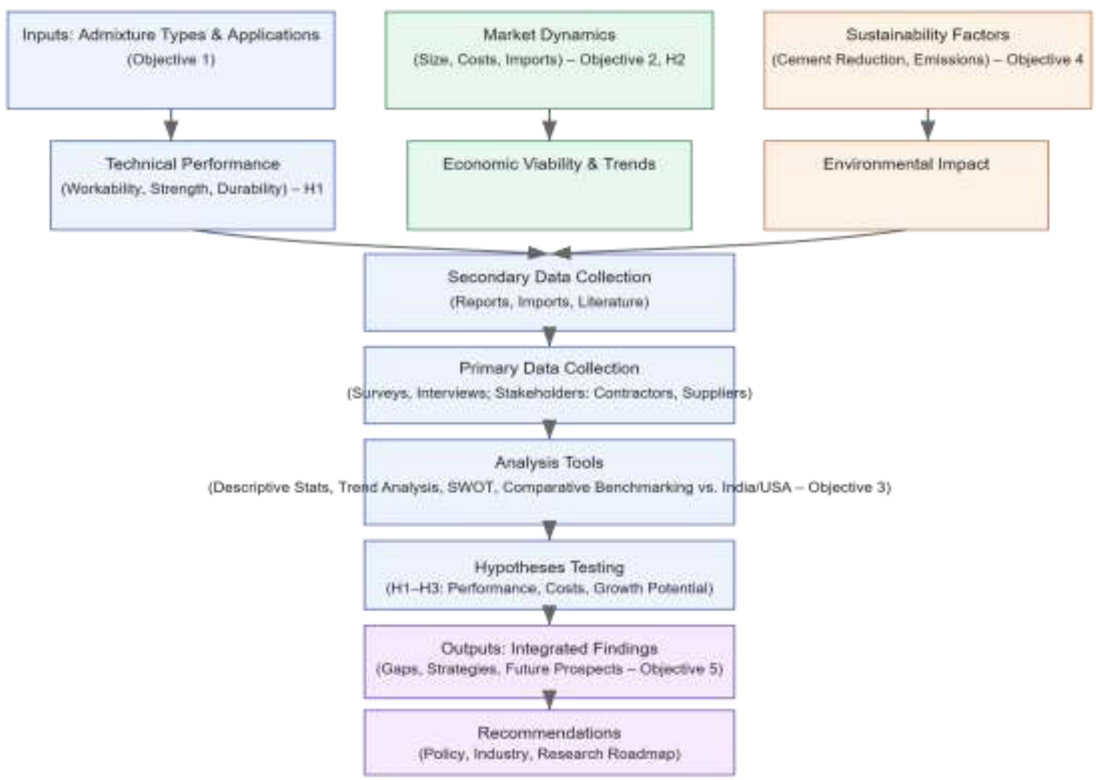

Figure 1: Research Model

The method of survey allows for direct assessment of the practices carried out in the industry while descriptive and relational statistical tools ensure that results are based on evidence rather than an anecdotal nature. This integrated framework helps to increase the contribution of the study by the relation between technical performance perception and market realities and accordingly makes the work actionable to researchers, industry stakeholders and policy makers.

4 Results and Discussion

4.1 Samples Characteristics & Credibility of Data

The basis of the analysis are 367 valid responses of professionals, who are actually involved in concrete production (design, procurement and execution of the construction) in real. The make-up of respondents would suggest the reasonableness of the relevance of the practice to be high - contractors/builders (25.1%) and consultants/design engineers (24.0%) account for nearly half the sample followed by suppliers/technical managers (20.2%) and clients/developers (13.1%), with a lesser representation from academia (9.5%) and government/regulatory bodies (8.2%), Figure-1.

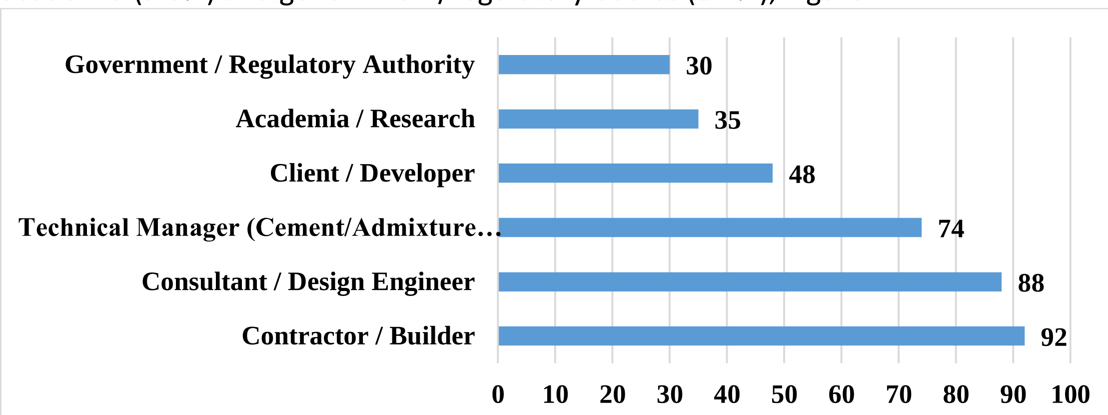

Figure 2: Distribution of Respondents by Professional Role

The data set is also experienced: only 18.0% have not more than five years experiences while 82.0% had more than five years and 53.7% has more than ten years' experience. Regionally response of all major markets with domination in Punjab (42.0%), Sindh (25.1%) though includes KP (13.9%), ICT/nationwide (8.4%), Balochistan (7.6%) and GB/AJK (3.0%). Organizationally, the picture is fairly clear with the private construction firms (40.6%) and consultant (25.1%) as overwhelmingly adopted practices which reflect the behavior of life span adoption for cost-competitive delivery systems. The results are reflective of actual adoption behaviour as roles involved in the selection, specification, payment and execution of polymer-based concrete solutions are the bulk of the sample in Pakistan.

4.2 Different Types of Polymers Used and Their Application

According to the survey findings, the use of polymer systems in Pakistan's construction sector is mainly driven by polymers used in admixtures, with polycarboxylate ether (PCE) and sulphonated naphthalene formaldehyde (SNF) being the most pertinent systems owing to their ability to increase workability and decrease water-to-cement ratios. They are widely applied in ready-mix concrete and major construction works, where the aim is to ensure quality of performance. But the study demonstrates that polymer usage in Pakistan is not restricted to admixture use. Much of the usage is related to application-based polymer systems, notably in niche construction works. Styrene-butadiene rubber (SBR) latex is widely employed in repair applications, plaster and waterproofing because of its excellent bonding and waterproofing properties. Likewise, polymer-modified mortars and plaster coatings are often used in repair and protection works, particularly for water-retainers and exposed to external elements. Furthermore, resin-based polymers such as epoxy systems are employed in industrial flooring and crack repair, but have limited use due to high cost and technical expertise needed in their application. PUR (polyurethane) coatings are also used for waterproofing and flexible coatings, especially in roofing and exterior applications in which crack-bridging and toughness are needed.

Table 1: Types and Applications of Polymers

Polymer Type	Form	Typical Application	Key Function
PCE / SNF	Admixture	Concrete production	Workability, water reduction
SBR Latex	Liquid polymer	Repair, plaster, waterproofing	Bonding, impermeability
RDP	Powder	Tile adhesive, dry mortars	Flexibility, adhesion
Polymer Mortars	Prepackaged	Structural repair	Durability, consistency
Cementitious Polymer Coatings	Slurry (2-component)	Waterproofing, protection	Crack-bridging, impermeability
Epoxy Systems	Resin	Flooring, crack repair	Strength, chemical resistance
Polyester Resin	Resin	Precast, rapid repair	Fast curing, high strength
PU Coatings	Liquid coating	Waterproofing, roofing	Flexibility, crack bridging

The survey results also substantiate that the polymer usage in Pakistan is highly oriented towards systems that have been identified in the questionnaire according to the application. SBR latex, redispersible polymer powders, pre-packaged repair mortars are all common materials used in plaster modification, tile adhesives and structural rehabilitation. Moreover, major applications of epoxy-based systems are the industrial flooring and the repair of cracks, whereas polyester resin-based systems are confined to special pre cast and quick repair applications. Polyurethane coatings are used in flexible and crack-bridging waterproofing and protection systems. This implies that polymer usage in Pakistan is not confined to admixture-based applications but is also very far-reaching to the system of surface protection, repair, and strengthening.

4.2.1 Sports equipment-Polymer types being used in Pakistan

A hybrid structure of adoption is present in the market. The highest number of polymers reported (51.0%) are polycarboxylate ether type (PCE), which means that there is a strong tendency to use high-range water reducer and performance admixtures. However, conventional and cost driven systems are still very large on the market: lignosulphonates (48.0%) and SNF based polymers (39.2%) are still very widely used, which confirms that the choice of technology is not only driven by performance consideration but also by affordability and familiarity. Penetration of SMF-based polymers is less (19.1%) and other types of polymers have less penetration (9.7%).

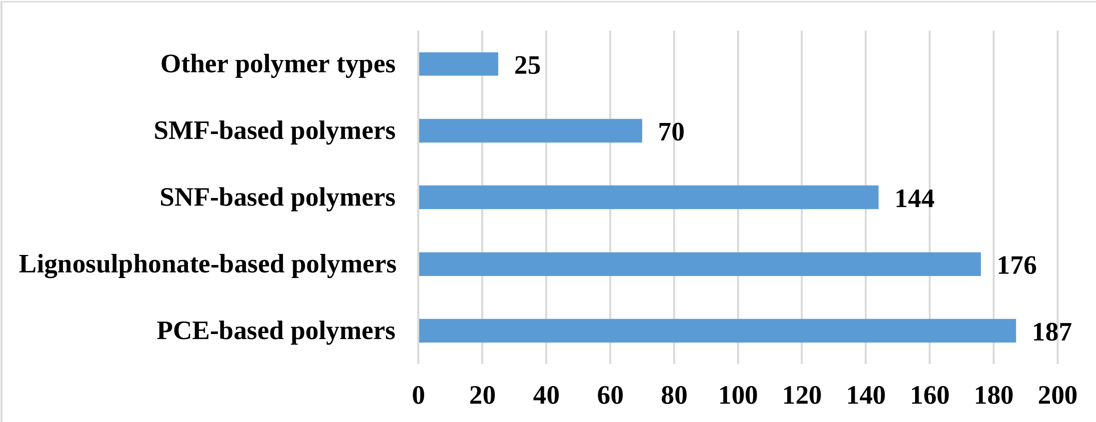

Figure 3: Types of Polymer-Based Admixtures Used

Pakistan polymer market is in a transition phase in which advanced adoption of PCE is increasing but conventional polymers are structurally important with regards to cost and procurement habits.

4.2.2 Areas of application: Sectoral penetration

Polymer adoption is very concentrated in vertical construction of buildings. The largest application is in high-rise building (56.9%) followed by applications in small housing projects (38.1%). Penetration is low in infrastructure and highways (26.4%) and major infrastructure (bridges/dams/flyovers/tunnels: 21,3%) and industrial structures (19,1%) and precast works (16,9%) which is comparatively low.

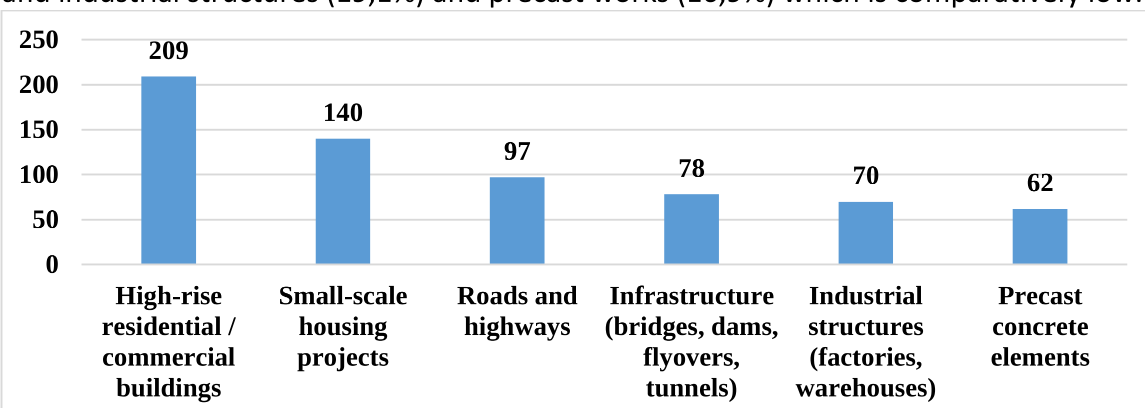

Figure 4: Application Frequency of Polymers Across Project Types

Adoption is far from uniform and polymers are utilised where constructability is a high risk (high-rise) however, are underutilised in precast and infrastructure where requirements for performance based procurement and durability testing are usually present but not always enforced.

4.3 Technical Performance of Polymer Based Materials

In addition, perceived technical performance was evaluated with the help of Likert scale analysis as workability, strength, durability and compatibility. Workability improvement has the highest percentage of confirmed benefits: 63.0% agree/strongly agree (42.0% + 21.0%) and with a mean of 3.70, the highest trusted and most consistently experienced benefit.

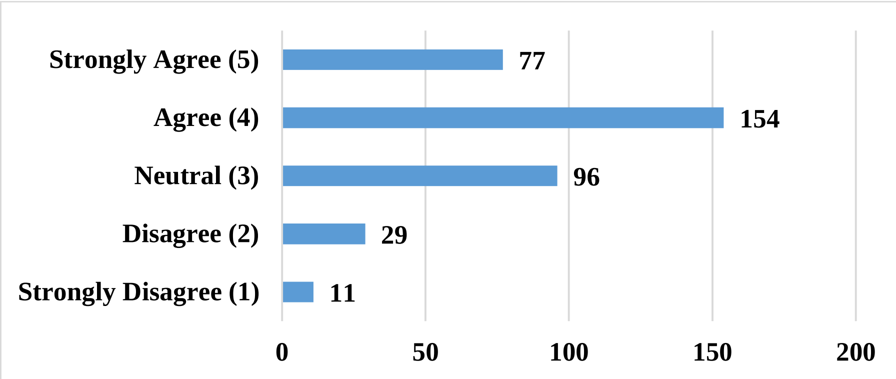

Figure 5: Perception of Workability Improvement Due to Polymer Use

Strength development was supported moderately with 53.7% of the respondents agreeing or strongly agreeing (29.7%+15.5%) and a mean score of 3.52. However, there is also a high neutral response (32.2%), indicating some noticeably uncertain responses from practitioners. This leads to the starting point in suggesting that while polymers are regarded as providing strength, the effectiveness of the polymer is not an automatic process, but delivers their effectiveness with a strong dependency on the proper control over mix design, dosage accuracy, and curing discipline.

For the improvement of durability, perceptions were comparatively weaker. Only 44.7% indicated agreement with a mean score of 3.36 and the largest response group was neutral (35.7%). This indicates a cautious confidence and reflects practical situations in the field where durability benefits might be associational from polymers may not be always make it via material quality, workmanship, and putting otherwise within the environment. Project compatibility came out as weakest technical dimension.

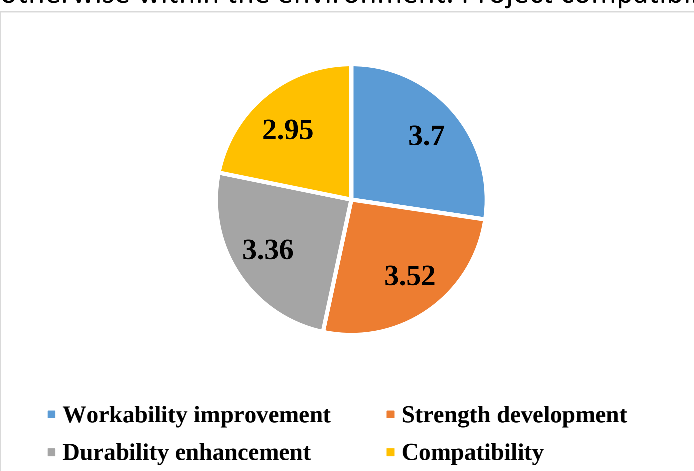

Figure 6: Mean Score Comparison of Technical Performance Parameters

Here, neutral responses (35.7%) outnumbered agreement (30.3%), and the mean score was reduced to a score of 2.95, suggestive of skepticism. This finding suggests the presence of real barriers to implementation, especially compatibility problems of cement with polymer materials and inconsistent procedures for pre-testing the cement-polymer base, as well as a lack of consistency in the local material used, which creates little confidence in predictable performance outcomes.

The results of the mean ranking (3.70 > 3.52 > 3.36 > 2.95) comparative practice summarize the overall picture: while practitioners clearly feel that polymers are more reliable for workability and strength-related improvements, the relative importance of durability and compatibility is currently representing an area of unclear and unstable technical relevance on the field.

Polymer-based materials are perceived to improve the technical performance as a whole - but with conditionality, with compatibility serving as a restriction factor for some inconsistency in the field.

4.4 Economic and Market Constraints That Determine Adoption

The constraint for adoption in Pakistan is not only technical usefulness since the fundamental economic risk is high. Cost perception price perception is high. 59.7% agree/ strongly agree that polymers are expensive. 37.1% + 22.6% = 60.1% Average = 3.61.

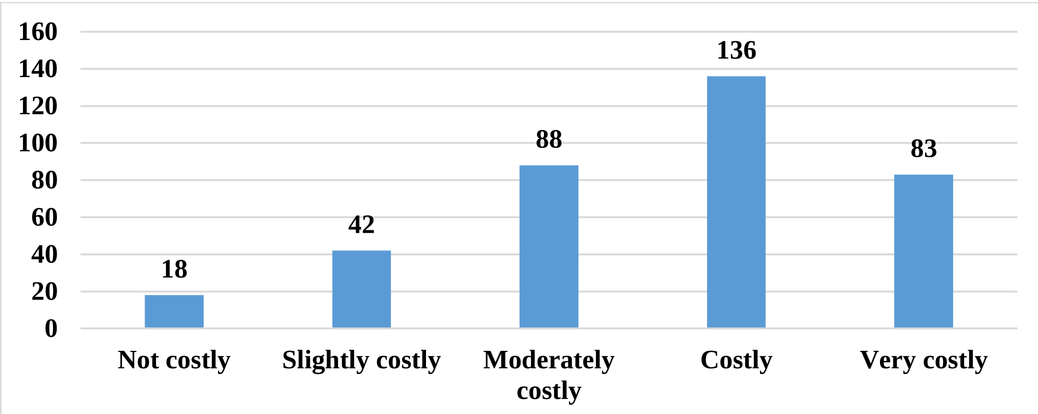

Figure 7: Perception of Cost of Polymer-Based Materials

Price volatility is the worst obstacle: 64.0% agree / strongly agree (36.0% + 28.0%), mean 3.74 which simply means, that it due to unpredictability which discourages specification and procurement. Import dependency is high in structural terms: high or very high rate dependency 65.4% (43.1% + 22.3%) which confirms exposure to exchange rate risk as well as supply instability.

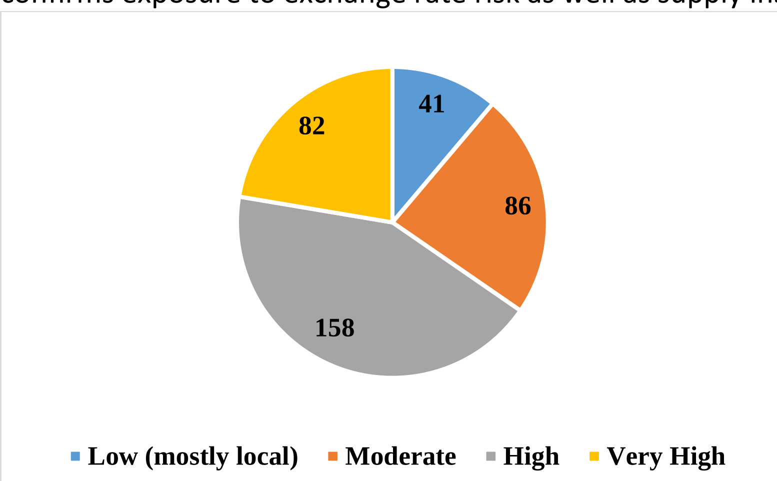

Figure 8: Import Dependency of Polymer-Based Materials

Availability is moderately positive: mean 3.38, 22.6% poor / very poor availability, hence indicating uneven distribution outside the greater urban markets. Stakeholder cost sensitivity explains the behaviour of value engineering. The cost can be seen as the main concern by clients/developers (mean

3.89), the next level is that of consultants (3.72) and contractors (3.58) whereas the cost sensitivity of suppliers (3.31), academia (3.22) and government (3.18) is relatively low.

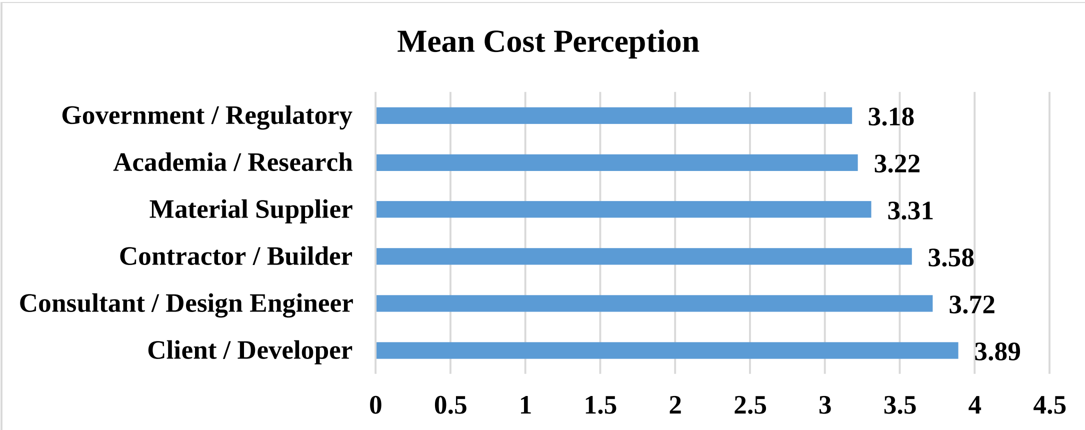

Figure 9: Cost Perception by Professional Role (Mean Scores)

Adoption is greatly influenced by high cost, volatility and dependence upon imported sources, with budget authority on the part of the client being the best driver in eliminating polymers during value engineering.

4.5 International Benchmarking

Benchmarking makes the adoption by Pakistan an institutional maturity issue rather than a technology availability issue. Compared to India, Pakistan is still project more specific and cost driven while the manufacturing in India has comparatively stronger and expanding standardization.

Table 2: Comparative Assessment – Pakistan and India

Sr No	Parameter	Pakistan	India
1	Polymer adoption level	Moderate, project-specific	Moderate to high
2	Dominant polymer types	Lignosulphonate, SNF, PCE	SNF, PCE, fiber polymers
3	Use in public infrastructure	Limited	Increasing
4	Local manufacturing capacity	Limited	Strong and expanding
5	Cost sensitivity	High	Moderate
6	Standards and codes	Limited local guidance	National standards available
7	Sustainability integration	Emerging	Moderately integrated

The benchmark in the UAE reflects the use of polymers normalised in robust enforcement, institutional training and regulation guided by sustainability, importance of cost as a factor in decision making has been minimised.

Table 3: Comparative Assessment – Pakistan and UAE

Sr No	Parameter	Pakistan	UAE
1	Polymer adoption level	Selective	Very high
2	Application areas	High-rise, repairs	All project types

3	Use of advanced polymers	Limited	Extensive
4	Specification enforcement	Weak	Strict
5	Sustainability focus	Emerging	Strong (green codes)
6	Price sensitivity	High	Low
7	Technical training	Limited	Institutionalized

The comparison to the USA reveals such a mature performance-based practice including mandatory compatibility testing, excellent QA, R&D support and regular lifecycle cost evaluation.

Table 4: Comparative Assessment – Pakistan and USA

Sr No	**Parameter**	**Pakistan**	**USA**
1	Polymer use maturity	Developing	Highly mature
2	Performance-based specifications	Rare	Standard practice
3	Compatibility testing	Limited	Mandatory
4	Local R&D support	Minimal	Strong
5	Lifecycle cost evaluation	Rare	Routine
6	Sustainability integration	Emerging	Embedded
7	Market stability	Volatile	Stable

The synthesis (Table 4.20) shows a very defined maturity ladder: Pakistan (developing) > India (semi-mature) > UAE (advanced) > USA (mature) The adoption drivers go from cost/constructability to performance, followed by regulation, and ended by lifecycle value.

Pakistan's strategic use is in line with its own ecosystem: as enforcement is weak and life cycle scarce the use of polymers is voluntary whereas in established markets polymer performance is institutionalised through regulation and testing and stable supply structures.

4.6 Implications to Sustainability and Environment

Sustainability Perceptions Positive but not fully institutionalised Cement reduction potential is 56.1% agreement (with 35.7% agree + 20.4% strongly agree), with mean score value = 3.55, (global 27.5% neutral) which means there is awareness but it has not come into implementation and verification yet. Lifecycle benefits also show great agreement (36.5% + 19.3%) 55.8%, mean 3.56 but neutrality is high (29.7%) which suggests not much routine use of formal lifecycle evaluation frameworks. Sustainability awareness distribution show 81.7% moderate to High (41.7% Moderate + 40.0% High), but 18.3% Low And the results show Durability awareness is conceptually linked to sustainability understanding.

Table 5: Relationship Between Durability and Sustainability Awareness

Sr No	**Sustainability Awareness Level**	**Percentage of Respondents (%)**
1	Low	18.3
2	Moderate	41.7
3	High	40.0

Polymer based materials are observed to have contributions to sustainability mainly through durability (associated mechanisms) i.e. service life and reduced maintenance, but sustainability is a secondary consideration to cost up front in the decision making process.

4.7 Combined Interpretation and Key Take Home Messages

Across the technical, economic, benchmarking, and sustainability results there is a consistent pattern of adoption, with polymers most widely adopted where it addresses immediate problems at a site (particularly workability), but adoption limited by economic instability and institutional limitations. The driving force that is the most powerful from a technical point of view is workability (mean 3.70) and the constraints that are the most powerful are price volatility (mean 3.74) and high import dependence (65.4%). Compatibility concerns (mean 2.95) is a concern of the variable user confidence, and contributes to the need for pre-testing and performance-based specifications. The benchmarking synthesis further confirms the fact that the countries with robust enforcement and testing culture and lifecycle decision making institutionalize polymers independent of the initial cost premiums. These results collectively inform the conclusion that the market of polymer is technically good but structurally constricted and to support the requirements for building a stronger, more stable polymer market in Pakistan; interventions in supply chain of stabilising supply, building local manufacture and to include aspects of performance/lifecycle metrics into specifications and procurement.

4.8 Advanced Analyse the Polymer Adoption Dynamics

Beyond descriptive statistics, the empirical results show a systematic structure of the interaction between technical performance, market forces, stakeholder behaviour and institutional maturity. This section attempts to interpret the dataset in the context of explanation to understand the reasons for selective adoption of polymer-based materials in spite of known benefits from a technical standpoint of the material, in Pakistan.

4.8.1 Performance - Adoption Gap

A key analytical insight which comes out of the data can be summarized as below, there is the performance-adoption gap. Technical indicators reflects on evidently positive perceptions: Workability improvement registered the biggest mean (3.70) with 63% agreement, the strength development (mean, 3.52) and durability enhancement (mean, 3.36) are evaluated positively. These findings are testament of the fact that the engineering community knows polymers as performance-improving materials. However, application data show adoption has taken place in a concentrated form, mainly in high-rise buildings (56.9%), repair works with a far less adoption in precast (16.9%) and infrastructure (from 21-26%).

Table 6: Performance–Adoption Gap Model

Variable	Empirical Indicator	Mean Score / %	Interpretation
Workability benefit	Strongest technical driver	Mean 3.70, 63% agree	Visible site advantage
Strength benefit	Moderate driver	Mean 3.52	Conditional on QC
Durability benefit	Long-term benefit	Mean 3.36	Weakly verified in practice
Compatibility	Technical risk	Mean 2.95	Performance unpredictability
Price volatility	Market risk	Mean 3.74	Strongest adoption constraint
Import dependency	Structural risk	65.4% high/very high	Supply & cost instability

Such a discrepancy is one indicator that adoption decisions are not based only on the perception of the performance. Instead, adoption is moderated by the predictability of the risk. Compatibility uncertainty (mean 2.95), price volatility (mean 3.74) and high import dependency (65.4%) are factors all contributing to perceived execution and monetary risk. Thus, what is lacking in this space then is not technical merit, but rather confidence of the industry for consistent and predictable outcomes. The data thus shows that Pakistani polymer market is risk averse as against to technology averse.

4.8.2 Hierarchy of Decision Driving

Comparative analysis of mean scores reveals some order between the drivers and constraints affecting adoption. Workability benefit (mean 3.70) becomes the strongest driver in terms of technical because it gives immediate and visible site benefits. In contrast, long term benefits, such as durability (3.36) and lifecycle performance (3.56) are lower down the decision influence spectrum. On the constraint side, price volatility (374) is higher than even cost perception (3.61), which is suggestive of more deterrence power to uncertainly in the pricing than costs amount.

Table 7: Hierarchy of Drivers and Constraints

Rank	Factor Type	Variable	Mean Score	Role in Decision
1	Constraint	Price volatility	3.74	Strongest deterrent
2	Driver	Workability	3.70	Strongest promoter
3	Constraint	Cost perception	3.61	Financial barrier
4	Driver	Lifecycle benefit	3.56	Weak driver
5	Driver	Strength	3.52	Secondary
6	Driver	Durability	3.36	Long-term benefit
7	Constraint	Compatibility	2.95	Technical uncertainty

This hierarchy corresponds to the fact that adoption behavior is determined by a short term performance v. short term financial risk. Immediate gains in constructability is all for the use of polymer, but cost exposure unpredictability and variability of compatibility pay back to that incentive. Sustainability benefits although they seem to have the good perceptions are still not actual driving factors in decision making as they work on longer time horizons and are not as institutionalized in enforcement.

4.8.3 Stakeholder Cost Sensitive & Value Engineering

Role based analysis gives us more explanation. Clients and developers are likely to be the most sensitive to costs (mean 3.89) followed by consultants (3.72) and contractors (3.58). This divergence is responsible for a common theme in the industry, where polymers may initially be recommended in the design stages, from a viewpoints of performance, but removed later through value engineering when the authority for budgets moves into the hands of cost controlling stakeholders. Adoption outcomes are therefore not only a matter of technical evaluation, but is dependent on who has the financial decision-making power. This finding brings into focus the finding that adoption barriers are embedded in procurement governance structures and not just engineering judgement.

4.8.4 Technology Maturity Positioning

Based on international benchmarking, that leaves Pakistan where maturity, less air pollution, is created than in the case of constructability. In this stage polymers are used to achieve more immediate solutions they are not in the form of embedded standard performance materials but are sites of solution to a single site challenge. More mature markets move towards regulation driven (UAE) and lifecycle-value driven (USA) adoption, institutional mechanisms such as performance based specifications, compatibility testing protocols and lifecycle cost analysis as tools to reduce uncertainty and regularise the use of polymers. The comparison shows that maturity progression is not correlated very well with technology availability alone but has a high correlation with regulatory enforcement and domestic supply stability.

Table 8: Technology Maturity Positioning Framework

Adoption Stage	Primary Driver	Characteristics	Example Market
Stage 1	Awareness	Limited trial use	Emerging markets
Stage 2	Constructability	Problem-solving use, selective adoption	Pakistan
Stage 3	Regulation	Performance-based specs, training	UAE
Stage 4	Lifecycle Value	QA systems, LCCA, stable supply	USA

4.8.5 Gap in Over Transition of Sustainability

Sustainability indicators Illustrate more transition gap While 56% of our respondent pool admit to the reduction potential of cement as well as 55.8% of them to the lifecycle benefits, neutrality figures (around a 27-30%) are still quite high, suggesting that the technology is still not being implemented in practice. Sustainability awareness is therefore conceptual and is not institutionalized. Durability is currently seen still as a technical rather than an implementation of a strategic sustainability mechanism, which can ensure the generality of lifecycle environmental gains in procurement criteria. This reinforces the conclusion that the benefit of sustainability, whilst recognised, seems to remain secondary to considering cost and risk considerations.

4.8.6 Integrated Explanatory Model

Collectively, the results of analyses made above shows the use of polymers in Pakistan to be a four factor interaction model:

1. Technical effectiveness that provides the first motivation (especially workability), and
2. Economic risk factors (volatility, dependence on imports) were moderating factors in making decisions,
3. Structures of governance at the stakeholder level, create an impact on final approval, and
4. Institutional maturity: defines whether lifecycle and sustainability benefits are internalized or not

Adoption is however still selective as these four dimensions are not remotely close to it on dimension. Until the compatibility testing and systems of supply stabilization and performance-based regulation are developed to minimize the degree of uncertainty, polymers will be applied as problem-solving tools rather than standardized building blocks of concrete technology.

5 Conclusions and Recommendations

5.1 Conclusions

This research that offers one of the foremost structured, industry-based assessment of adoption of polymer-based materials in construction sector of Pakistan by incorporating perception of technical performance, market restrictions and perception of sustainability and international benchmarking. The results, taken together, indicate that polymer-modified concrete is technically acknowledged as being beneficial and yet the existence of a selectivity in the adoption of the technology due to economic and institutional rather than technological limitations.

From a technical point of view, workability improvement was the most reproducibly recognised benefit (mean = 3.70), confirming if the polymers are much valued mostly for constructability benefits in complex concreting situations (e.g. high-rise construction). Strength (mean=about 3.52) and durability (mean=about 3.36) improvements are known as well, but felt a conditional on mix design quality and control of execution. Compatibility issues (mean = 2.95) are the biggest technical uncertainty that contribute to the fluctuation in field performance levels and decreased confidence of routine application.

The most significant moderating factors are economic and market factors. High perception of costs (mean approximates 3.61), price fluctuations (mean approximates 3.74) and high import dependency (approx65%) conjoinedly expect to limit wide adoption. The role-based analysis shows that clients and developers have the highest cost sensitivity and value engineering decisions are often made to eliminate polymer-based solutions in the face of technical recommendations. These results confirm the adoption of polymers in Pakistan to be economically restrained rather than technically restrained.

Sustainability finding show moderately positive awareness on the topic of cement reduction potential and lifecycle benefits (means = 2.84--3.56) however weakly institutionalized sustainability. Durability advantages are recognized but little discussed at the level of being considered lifecycle environmental strategies and the sustainability benefits occur indirectly, without use of the formal evaluation frameworks of lifecycle.

These outcomes are put in further context by international benchmarking. Normalized adoption of polymers is shown in countries that exhibit more mature approaches to regulatory enforcement, develop a domestic manufacturing capacity, establish an organized quality assurance systems and lifecycle-based decision frameworks (e.g. UAE, USA). Pakistan is in the constructability driven part of the maturity where the polymers are used not so much to specify how performance will be accomplished within a standard, but rather how to address issues at the site level.

Overall, the study concludes that the future growth of polymer-based materials in Pakistan is less about proving technical effectiveness, which is well accepted, and more on stabilising the economic situation and developing frameworks and incorporating evaluation on a lifecycle basis in decision making in the construction sector.

5.2 Practical Recommendations

For safe and systematic adoption of polymer-based materials in construction sector of the country i.e Pakistan, a concerted plan of technical, institutional and policy measures is required. Standardized testing in terms of cement - polymer compatibility, however, should be introduced through the development of national guidelines to reduce the level of performance uncertainty and increase the level of confidence to practitioners. In parallel, the local manufacture of polymer admixtures should be promoted in order to reduce the importance of the import dependency, stabilise the market prices and permit the formulation to be customised with the local availability of cement and aggregate. Structured professional training programmes for engineers, contractors and site supervisors to reinforce knowledge on the polymer technology, dosage control and optimized mix design practices to minimize variability in field performance of is definitely needed. Lifecycle cost evaluation (LCCA) should be a part of project appraisal structure to balance between short-term cost sensitivity and long-term performance and maintenance benefits to ensure that decision-making is reflective of durability and service life benefits rather than initial cost alone.

At the regulatory level, building codes and public procurement standards should contain performance based parameters relating to polymer modified concrete, and to shift the focus in the construction arena towards measurable results in terms of durability and lifecycle performance. Government agencies can provide further support to this transition process by incentivizing research and development responses between academics and industry on these local issues of compatibility, and building on technical solutions tailored to specific contexts. Sustainability requirements should also focus on the use of durable materials with less maintenance cycle and longer service life which also reinforces the environmental value of performance-oriented materials selection.

This research contributes to knowledge by providing a structural explanation to the dynamics of adoption of polymers on a growing construction market. It acknowledges a performance vs. adoption gap driven by predictability of risk, economic volatility and the institutional maturity and describes a maturity positioning framework that provides a relationship between the choice in adoption behaviours and strength of regulations and orientation of the technology lifecycle. This framework delivers a replicable model to comprehend the higher level of integrating material in similar economy. Future research should aim at experimental validation of compatibility and durability performance under local material conditions, quantitative lifecycle carbon assessment model development and examination of the role that policy and market interventions play in the growth of adoption and supply stability.

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