Vulnerability-Preventing Structures in Disaster Management: Polyurea Coating on Building Structural Elements

Afet Yönetiminde Zarar Görebilirliği Önleyici Yapılar: Bina Yapısal Elemanlarında Poliüre Kaplama

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ABSTRACT

Numerous disasters occur due to the inability to manage risks arising from natural, technological, and human-induced hazards. As a result of these disasters, the magnification of incurred damages underscores the significance of the concept of risk management, an integral step in disaster management. Consequently, efforts to mitigate the adverse effects of earthquakes and other disasters are progressively increasing. However, endeavors aimed at reducing the damages inflicted by earthquakes and other disasters on structures, particularly earthquakes, are not yet at an adequate level. Presently, the importance of alternative solution models to counteract the forces exerted on structures during disasters like earthquakes is on the rise.In this study, unreinforced concrete blocks were coated with flexible polyurea, a state-of-the-art cladding material extensively used in various fields, at different thicknesses. Three-point bending tests were performed on the coated specimens. The data obtained from these tests were analyzed and evaluated. It was concluded that specimens coated with polyurea exhibited higher strengths compared to uncoated specimens. This study introduces the utilization of polyurea flexible composite material in structural elements as an alternative method within the spectrum of precautions taken to enhance the safety of structures against various disasters, primarily earthquakes.

Keywords: Disaster Risk Management, Earthquakes, Seismic Risk Evaluation, Building Safety, Polyurea Composites

ÖZ

Doğal, teknolojik ve insan kaynaklı tehlikelerden ortaya çıkan risklerin yönetilememesi sonucunda birçok afet meydana gelmektedir. Yaşanan bu afetler sonucunda; oluşan zararların büyük boyutlara ulaşması, afet yönetiminin bir basamağı olan risk yönetimi kavramını önemli kılmaktadır. Bu nedenle depremler ve diğer afetlerin olumsuz etkilerini önlemeye yönelik çalışmaların sayısı her geçen gün artmaktadır. Depremler başta olmak üzere diğer afetlerin yapılara verdiği zararları azaltmak ve mümkünse bu zararları önlemeye yönelik çalışmalar henüz yeterli düzeyde değildir. Günümüzde deprem gibi afetlerde yapılara etkiyen kuvvetleri karşılamaya yönelik olarak alternatif çözüm modellerinin önemi giderek artmaktadır. Bu çalışmada donatısız beton bloklar, yeni nesil bir kaplama malzemesi olan ve birçok alanda sıkça kullanılan esnek poliüre kaplama malzemesi ile faklı kalınlıklarda kaplanmıştır. Kaplanmış olan numuneler üzerinde 3 noktalı eğilme testi gerçekleştirilmiştir. Bu testlerden elde edilen veriler analiz edilerek değerlendirilmiştir. Poliüre ile kaplı numunelerin, poliüre ile kaplanmamış numunelere göre mukavemetlerinin yüksek çıktığı sonucuna varılmıştır. Bu çalışma yapı elemanlarında poliüre esnek kompozit malzemesinin kullanılması ile deprem başta olmak üzere diğer pek çok afete karşı yapıların güvenliğini artırmaya yönelik olarak alınan önlemler içerisinde alternatif bir yöntem olarak sunulmuştur.

Anahtar Kelimeler: Afet Risk Yönetimi, Depremler, Sismik Risk Değerlendirme, Yapı Güvenliği, Poliüre Kompozitler

Bu makale birinci yazarın yüksek lisans tezinden üretilmiştir.

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INTRODUCTION

Any nature, human or technology-induced situation that has the risk of harming living things and the environment and leads to large-scale adverse events in the society and ecosystem when occurs, giving rise to substantial physical economic and social losses and rendering the existing resources insufficient, can be described as a disaster.[1] The inability to manage the the disasters, the increasing uncertainties in relation thereto and the enormous extent of the damages caused by disasters render the the concept of risk management in disaster management vitally important. Disaster management can be described as preventing the existing risks from becoming a disaster or as reducing the possible effects of a disaster that may occur.[2] According to the 2021 Global Natural Disasters Report, natural disasters experienced worldwide last year, the earthquakes in particular, gave rise to 343 billion dollars in economic losses.[3] Factors such as unplanned urbanization in densely populated cities, inadequate engineering services for buildings, lack of audits, unplanned industrialization, and lack of studies to analyze and reduce the earthquake risks further add up to the already high disaster risks associated with earthquakes.[2] According to the Global Natural Disaster Assessment Report; 245 million people were affected by the earthquakes between 1991 and 2000, of whom 6095 lost their lives, and the related direct economic losses amounted to US$ 29.6 billion; 87 million people were affected by the earthquakes between 2001 and 2010, of whom 68015 lost their lives, and the related direct economic losses amounted to US$ 27.7 billion; 283 million people were affected by the earthquakes between 2011 and 2020, of whom 4019 lost their lives, and the related direct economic losses amounted to US$ 37.4 billion; 109 million people were affected by the earthquakes in 2021 alone, of whom 2742 lost their lives, and the related direct economic losses amounted to US$ 11.3 billion.[3] The disaster management works mainly focus on the intervention and recovery phases, which are post-disaster phases, in the case of earthquakes. However, it is beyond doubt that in order to overcome the disasters, especially earthquakes, with the least damage, predisaster works should constitute the focus of disaster management works. As a matter of fact, the increase in the frequency of disasters and their impact areas with each passing day prompted researchers to focus more on the pre-disaster works in recent years.[2] Earthquake risk management is defined as the systematic development of comprehensive sustainable policies and strategies and the implementation of these policies and strategies in order to minimize, prevent or limit the earthquake risks and the related vulnerabilities in a society. Given the uncertainties and complexity inherent in earthquakes, the studies on the related risk management processes differ greatly; yet, they all pursue the same objective, that is, to manage the related risks in an effective manner, carry out mitigation activities, increase social capacities, and thereby minimize any negative effects thereof.[4] In order to meet the need for earthquake resistant housing, diversified alternative solutions are being developed in the light of technological developments.[6,7] In parallel, given their properties of high strength, energy absorption and flexibility, composite materials have become widespread in the construction sector as in many other areas. In this context, the objective of this study is to obtain scientific data on the effect of coating the building elements with flexible polyurea spray materials with a view to preventing any vulnerabilities in face of disasters, on the strength of these elements and to offer solutions based on these scientific data.

Hazards, Risk Management and Unmanageable Risks

Hazards are characterized by an event or series of events in relation to which all human activities and service losses could result in great economic damages.[8] In other words, hazards are life-threatening physical events or phenomena that occur at a given time or geography.[9] In parallel, the definition of risk in disaster management is the possibility that a hazard which may potentially occur in the future damages the natural environment, humans and human activities.[10]

Accordingly, risk management aims maintaining the current status in the face of risks through planning, organization, management and control of the activities and resources necessary to contain the unexpected losses that may occur with the least damage.[11] Unmanageable risks are the factors that lead to processes such as incidents, emergencies, states of emergency, extraordinary situations, disasters and catastrophes, due to the insufficient capacity of the affected society to cope with escalating losses and damages in the event of occurrence of potential risks.[9,10]

Effects of Earthquakes on Structures

The effects of earthquakes on structures are of physical nature. Accordingly, earthquakes give rise to forward-backward and downward-upward oscillation movements on the structures which are connected to the ground through their foundations. These forces acting on the structures depend on various including the magnitude of the earthquake, the distance of the structures from the epicenter, the soil, geological formation characteristics, and physical properties of the structure. Structures react to these forces. These vibration-related forces and structures' reactions to these forces that are constantly changing direction continue until the earthquake energy comes to an end. In this process, the building elements begin to unravel from each other. The resistance of a structure against an earthquake depends on its height and the strength of its fasteners.[12] Various damages are observed in structures that do not respond appropriately to earthquakes, stemming from the architectural, construction and the usage processes of the structures.[13]

Earthquake Risk Management

In earthquake risk management, it is critical to be aware of the fact it is the vulnerability of the structures that primarily leads to loss of life and property in the event of earthquakes. Hence, constructing earthquake-resistant structures is the most important measure that can be taken against earthquakes.[14] To this end, it is essential to understand how nature works and earthquakes affect our structures and to make plans to that effect and implement these plans. Earthquake-resistant structures are designed in accordance with a scenario of a very severe earthquake that may potentially occur in a certain time period, in the relevant geographical region, at an estimated magnitude, with a certain probability. The first step of an effective earthquake risk management system is to analyze the hazards of the regions where the structures will be built and to plan the respective architectural designs in a way that allows the use of uncomplicated, robust load-bearing systems.[15] The second step of an effective earthquake risk management system is to ensure that the structures have solid foundations. Different types of soils require the building foundations to be reinforced in different ways. Therefore, it is very important to understand the soil properties well and to make the plans to that effect before starting the construction of the building. The earthquake resistance of buildings is related to how the structures move against a force exerted in the horizontal direction. Earthquake safety experts recommend that buildings be constructed in such a way that the seismic force acts equally in all parts of the buildings, and does not accumulate on only one side.

Weak points in the building design can cause damage when the building is shaken, resulting in damage to the entire building. Experts agree that more than one strategy should be used for earthquake resistance of buildings, so that if one strategy does not work, other strategies can factor in. Two important concepts in earthquake resistance that are complementary to each other is tensile strength and ductility. Ductility of structures must be ensured in accordance with the regulations in force so that the structure can absorb large amounts of energy preventing it from collapsing in the event of very severe earthquakes.[16]

Polyurea Coating

Polyurea, a type of composite material, has many intermolecular hydrogen bonds giving it excellent mechanical properties, including resistance to high tensile forces.[17] Given its unique properties and easy applicability, polyurea is used in many fields. Its resistance to atmospheric, chemical and biological factors and high resistance make polyurea a good choice for use in the construction industry, as well. With its excellent resistance to corrosion and wear, it strengthens the building materials and structures.

Polyurea coating technology is a green technology that does not cause environmental pollution and toxicity, and provides significant advantages over many other technologies in the construction industry. Hence, the use of polyurea composite systems in the construction industry is increasing in the context of the optimization of various properties such as mechanical and thermal properties of the building elements and reducing the relatated costs and economic burden.[18]

MATERIAL AND METHODS

Polyurea and properties of polyurea

Polyurea is synthesized from two reactants, i.e., isocyanate and polyamine, in a 1:1 ratio under high temperature and high pressure conditions.[19,20,21,22,23,24,25,17,26] Polyurea was obtained by reaction of diisocynate and polyamine.[27]

Polyurea spray coatings cure quickly even at sub-zero temperatures and have exceptional physical properties such as high hardness, flexibility, tear strength, tensile strength, chemical and water resistance. The synthesis reaction of polyurea takes place rapidly in a very short time, which allowd the reaction to proceed largely independent of ambient conditions and humidity and facilitates the application of polyurea under different conditions.[28,29,29,17,40b] Machines furnished with high pressure heating equipment, hoses resistant to high pressure and temperature, and a gun at the end of the hoses that mix polyurea components and spray are used in polyurea application.[17]

Areas of Use of Polyurea Coating

Its superior physical properties, e.g. high durability, high resistance to chemical and biological factors, provides for the use of polyurea coatings in many engineering projects, including but not limited to: [22,29,17]

- Various construction applications such as tunnels, bridges, roofs, parking lots, storage tanks, hard and wear-resistant, corrosion-resistant, long-lasting and impact-resistant (epoxy/rubber replacement) spray coating applications, cargo ships and truck beds,
- Sealing of pools, rain water gutters, and water tanks,
- Protection of parking lot floors from fire and in the elimination of floor slippery caused by sudden brakes and excessive speed,
- Closing and repairing cracks on old and new concrete structures, walls and roofs,
- Fire resistant structures and impact- and ballistic-resistant panels in military vehicles, and
- Protection of steel pipes and tanks used in the petrochemical industry against heavy chemicals and corrosive environments.

Experimental Studies

This study features the use of polyurea composite materials in the building sector against the seismic forces that the structures are exposed to based on the results of experimentals carried out on the potential use of polyurea composite materials in concrete blocks with a view to reducing and eliminating earthquake-induced damages on structures. Experimental phase of the study has been carried out in three stages. To this end, first, unreinforced concrete block samples were made. Secondly, polyurea composite material has been procured and then applied on these samples placed in different floors. Thirdly, the samples were tested using the three-point bending test in order to determine their seismic properties.

- **Making of Unreinforced Concrete Block Samples**

The unreinforced concrete block samples were made in the Laboratory of the Department of Civil Engineering of Gümüşhane University TS 802 standard of TSE (Turkish Standards Institution). All of the concrete block samples were made in dimensions of 10x10x40 cm.

- **Coating the Unreinforced Concrete Block Samples with the Procured Polyurea Composite Material**

Polyurea polyurea composite material is applied on surface using machines furnished with high pressure heating equipment. The coating of the unreinforced concrete block samples with the procured polyurea composite material was outsourced to a commercial company, since the said machines were not available at the laboratory, where this study was conducted. Accordingly, the three unreinforced concrete block samples of 10x10x40 cm dimensions made at the laboratory were coated with 2, 4 and 6 layers of the polyurea composite material, respectively (Figures 2a).

Care was taken to ensure that the unreinforced concrete block samples were clean and dry, free from dust, oil and other residues during the coating application.

- **Performing the 3-Point Bending Test on the Unreinforced Concrete Block Samples**

The 3-point bending test is performed to determine the strength of the material and the mechanical properties of the material against bending. All structural elements, such as concrete blocks, which are exposed to horizontal loads during an earthquake, are subject to bending. In order to perform conventional bending tests, the surfaces of concrete samples must be homogeneously coated. Per the TS 205 standard of TSE, the 3-point bending test assesses the deformation that occurs when a force is applied to the middle of a flat sample, usually with a circular or rectangular cross section, which is freely placed on two supports. The 3-point bending test is commonly performed on fragile and brittle materials such as cast irons, high strength steels and composite materials.

The 3-point bending test was performed on six unreinforced concrete block samples, 3 coated with polyurea and 3 uncoated (Figures 2b). The 3-point bending testing apparatus was setup in accordance with TS-3114. The samples, which were produced in 10x10x40 cm dimensions, were tested using the 3-point bending testing apparatus 28 days after they were produced per the TS-3114 standard. Accordingly, the samples were automatically broken and the breaking loads and compressive stresses were calculated.

- **The Results of the 3-Point Bending Test**

The maximum force ((the force (kN) that the sample can bear)), maximum energy ((total energy (Joules) that the sample can absorb till it breaks)) and deflection ((the deflection (mm) between the initial state and final state of the sample)) values of the polyurea-coated and reference samples of different thicknesses (2, 4 and 6 layers) are given in Table 1.

Table 1. Force, energy and deflection values of unreinforced concrete samples measured by 3-point bending test.

Beam Samples	Max. Force (kN)	Max. Energy (Joule)	Deflection (mm)
Reference Sample 1	5,13	0,97	0,91
Reference Sample 2	5,53	1,17	0,95
Reference Sample 3	5,37	1,04	0,92
Sample Coated with 2 Layers of Polyurea	5,94	377,68	104,90
Sample Coated with 4 Layers of Polyurea	4,37	234,27	85,74
Sample Coated with 6 Layers of Polyurea	3,09	146,90	68,37

In addition, the Force-Deflection and Energy-Deflection data of the samples are shown in Figures 1a, 1b, 1c, 1d, 1e, 1f, 1g, 1h, 1i, 1j, 1k, and 1l. The force, energy and deflection values of the unreinforced concrete samples are shown in the Figures below, respectively.

The amount of deflection, which determines the energy absorption (toughness) capacity, increased at a higher rate in the polyurea-coated concrete samples than in the uncoated (reference) samples. The brittle fracture in reference samples with a small amount of deflection can be seen in Figure 2c. The deflection tendency of the sample coated with 2 layers of polyurea is shown in Figure 2e. The deflection tendency of the sample coated with 4 layers of polyurea is shown in Figure 2e. The deflection tendency of the sample coated with 6 layers of polyurea is shown in Figure 2f. Polyurea-coated samples broke by exhibiting ductile behavior. However, the amount of deflection decreased with the increase in polyurea coating thickness. Accordingly, the amount of deflection was the highest in the sample coated with 2 layers of polyurea (Figure 2d), and less in samples coated with 2 and 4 layers of polyurea (Figures 2e and 2f).

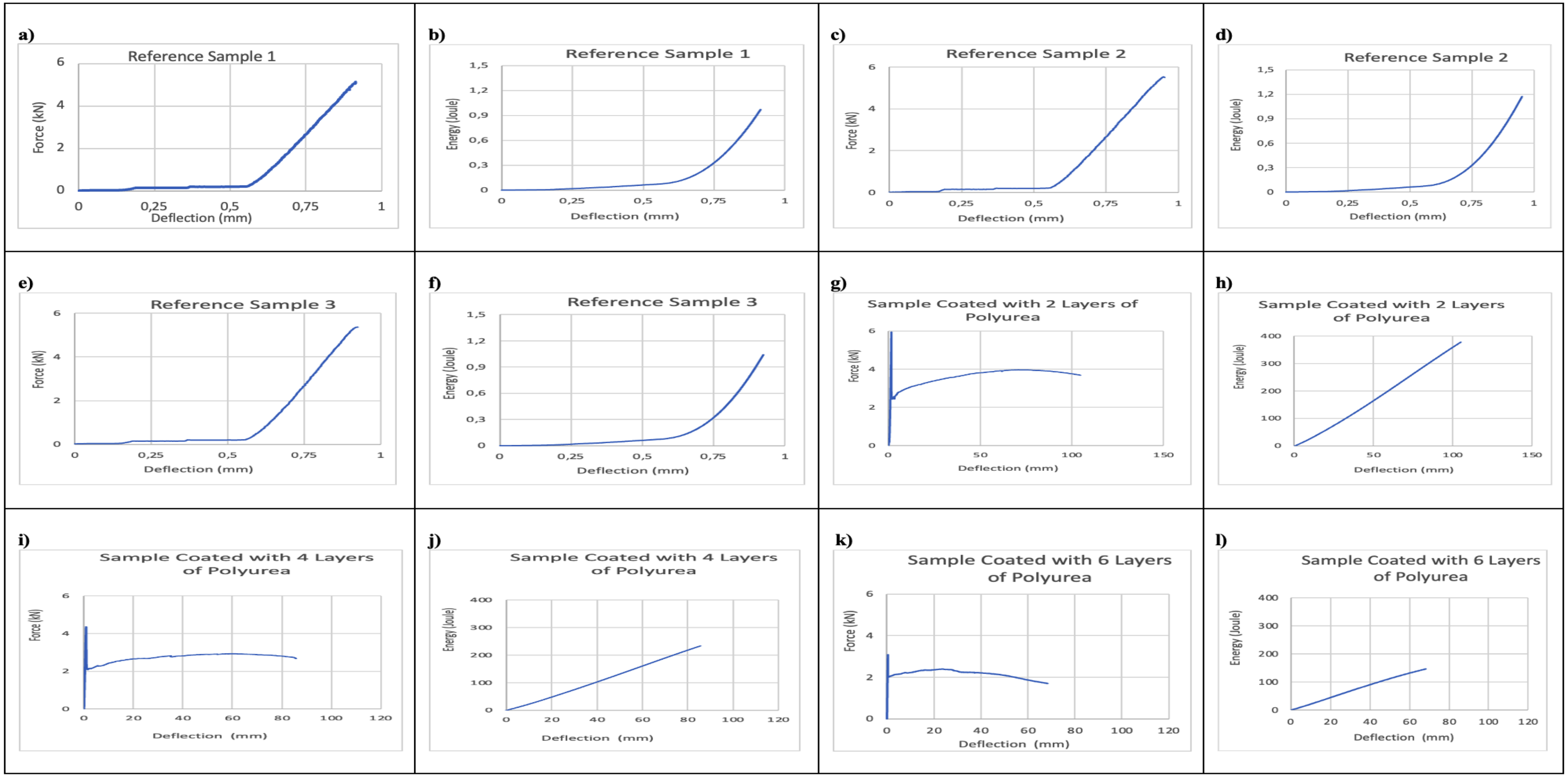

Figure 1. a) Force-deflection relationship of reference sample 1 (5.13 kN-0.91 mm).**b)** Energy-deflection relationship of reference sample 1 (0.97 J-0.91 mm). **c)** Force-deflection relationship of reference sample 2 (5.53 kN-0.95 mm). **d)**Energy-deflection relationship of reference sample 2 (1.17 J-0.95 mm).**e)** Force-deflection relationship of reference sample 3 (5.37 kN-0.92 mm).**f)** Energy-deflection relationship of reference sample 3 (1.04 J-0.92 mm).**g)** Force-deflection relationship of the sample coated with 2 layers of polyurea (5.94 kN- 104.90 mm). **h)** Energy-deflection relationship of the sample coated with 2 layers of polyurea (377.68 J – 105.904 mm).**i)** Force-deflection relationship of the sample coated with 4 layers of polyurea (4.37 kN-85.74 mm).**j)** Energy-deflection relationship of the sample coated with 4 layers of polyurea (234.27 J- 85.74 mm).**k)** Force-deflection relationship of the sample coated with 6 layers of polyurea (3.09 kN - 68.37 mm).**l)** Energy-deflection relationship of the sample coated with 6 layers of polyurea (146.90 J- 68.37 mm).

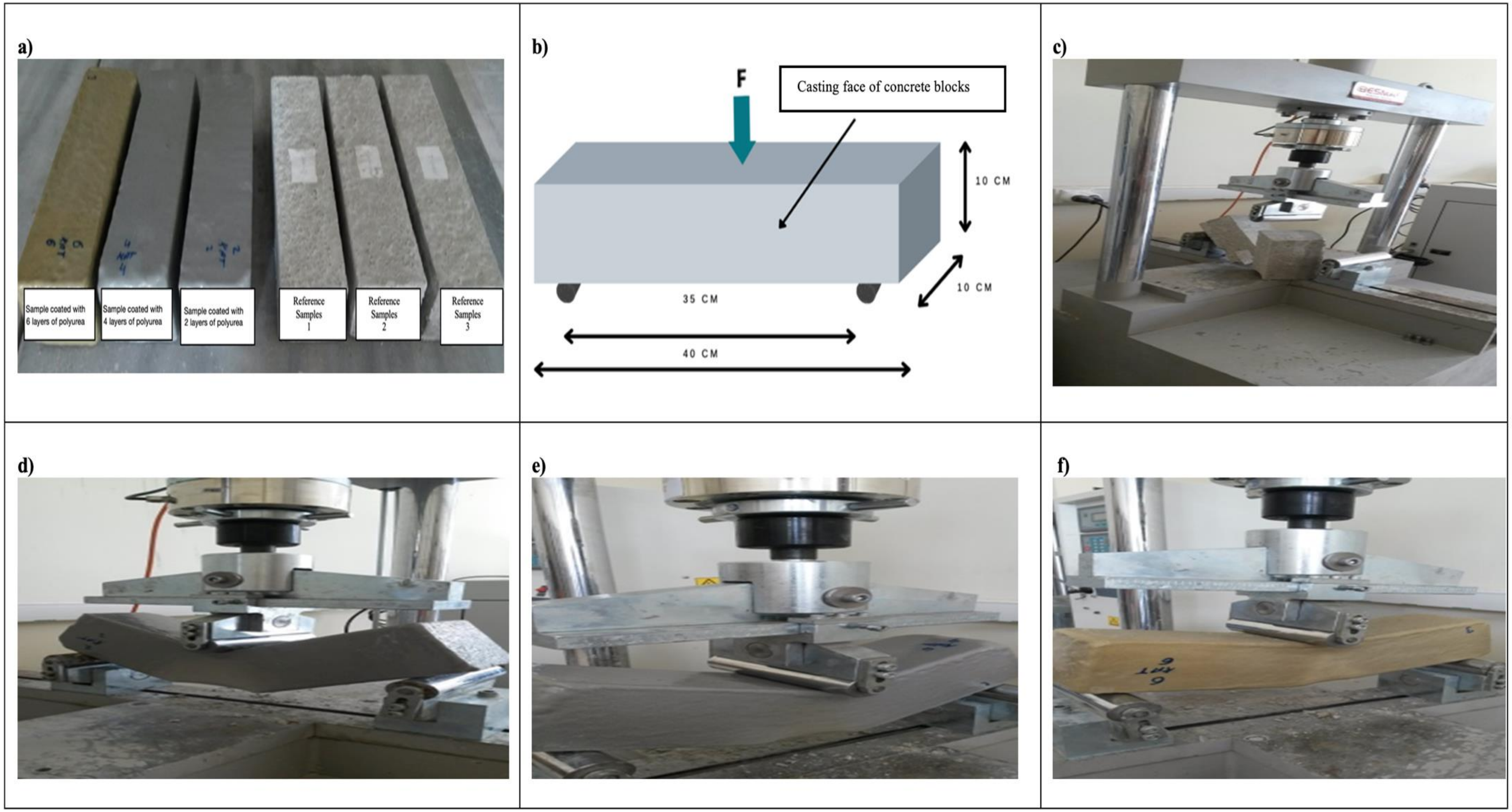

Figure 2. a) Polyurea-coated and uncoated (reference) concrete samples. **b)**3 Point Bending Testing apparatus. **c)** Brittle fracture in reference samples 1, 2, and 3 without deflection. **d)** Deflection in the sample coated with 2 layers of polyurea. **e)** Deflection in the sample coated with 4 layers of polyurea. **f)** Deflection in the sample coated with 6 layers of polyure

RESULTS AND DISCUSSION

The results of the analyses shown in Table 2 indicated that the concrete samples coated with flexible polyurea spray material had higher strength and load carrying capacities compared to the uncoated (reference) concrete samples.

Table 2. Strength, deflection and toughness values of polyurea-coated concrete samples compared to reference concrete samples.

Samples	Max. Force (kN)	Max. Deflection (mm)	Toughness (Joule)	Force Rate	Deflection Rate	Toughness Rate
Reference Samples 1, 2, 3	5,34	0,93	1,06	0%	0%	0%
Sample coated with 2 layers of polyurea	5,94	104,9	377,68	11%	11180%	35530%
Sample coated with 4 layers of polyurea	4.37	85,74	234,27	-18%	9119%	22001%
Sample coated with 6 layers of polyurea	3,09	68,37	146,9	-42%	7252%	13758%

In the study conducted to investigate the polyurea-coated aluminum sheets of different thicknesses under impact, Mohotti et al. (2014) determined that polyurea-coated sheets absorb less energy compared to uncoated sheets in the event of impacts,[30] which suggests that polyurea can be used as an efficient energy absorbing material against low velocity impact damage. In another study conducted by Yıldırım (2019), polyurea-coated armor plates performed better in terms of strength than uncoated armor plates when subjected to ballistic tests in order to determine their impact resistance.[17-40c] Similarly, in a study conducted by Liu et al., (2021) polyurea-coated carbon fiber reinforced plastic (CFRP) performed better than uncoated CFRP in terms of ballistic resistance. [31]

In another study (Ackland et al., 2013), the impact strength and impact resistance of polyurea-coated steel plates were found to be higher than those of uncoated steel plates when subjected to explosion.[32] In a similar study (Xue et al., 2010) polyurea-coated were found to be superior to uncoated DH-36 steel plates in penetration behavior, energy absorption, and thereby resistance. [33]

In parallel, the temperature of the polyurea-coated samples increased during the 3-point bending tests conducted within the scope of this study, suggesting that polyurea coating absorbed the energy and converted it to heat energy. As a matter of fact, in a study (Grujicic et al., 2010) on the relationship between the glass transition temperature (Tg) of polyurea and the absorption mechanism between its deformation in order to elucidate the characteristics of polyurea underlying its high elasticity and excellent abrasion resistance and mechanical properties, ballistic experiments performed on polyurea coated sheets revealed that the the polyurea ply sheets get heated and exhibit either a ductile or energy absorbing behavior depending on whether there is a high or low difference between Tg of the polyurea and the magnitude of the impact, respectively. This result suggests that the behavior of polyurea is associated with viscous energy distribution, which may contribute to its superior ballistic and blast energy conservation capacity (Grujicic et al., 2010). A similar (Amini et al., 2010) investigating the deformation patterns of polyurea-coated steel plates subjected to direct pressure revealed that the polyurea coating applied to the front surface (impacted side) of the plate increased the deformation of the plate with the effect of the first impact, and hence that more successful results were achieved when the polyurea coating was applied to the back surface of the plate.[34] In a study conducted by Ha et al. (2011) comparing highly stiff and strong carbon fiber reinforced polymer (CFRP) and high ductility polyurea materials in terms of providing better protection against explosion or impact, it was found that the polyurea coating on the surface that is not directly exposed to the explosion gave more effective results in terms of displacement control, suggesting that the polyurea composite material was more durable under an explosion than the typical reinforced materials, i.e. CFRP.[35]

In another study conducted by Toader et al., (2016) a series of polyurea derivatives were developed for ballistic protection, and tested using Fourier-transform infrared spectroscopy (FTIR), thermal measurements, tensile tests and scanning electron microscopy for ballistic protection. Consequently, it was found that only the polymer synthesized from zinc phthalocyanine exhibited both high stress and high tensile values, clearly suggesting that polyurea is a good candidate among composite materials for use in ballistic protection.[36]

Variation of the force acting on polyurea-coated concrete samples of different thicknesses is shown in Figure 3a.

The results of this study revealed that the concrete sample coated with 2 layers of flexible polyurea spray material had 11% higher maximum load carrying capacity than those of the reference samples. On the other hand, the maximum load carrying capacities of the concrete samples coated with 4 and 6 layers of polyurea were lower than that of the concrete sample coated with 2 layers of polyurea. This result is attributed The results of this study revealed that the concrete sample coated with 2 layers of flexible polyurea spray material had 11% higher maximum load carrying capacity than those of the reference samples. On the other hand, the maximum load carrying capacities of the concrete samples coated with 4 and 6 layers of polyurea were lower than that of the concrete sample coated with 2 layers of polyurea. This result is attributed to the fact that the polyurea coating above a certain thickness becomes the primary barrier against the load which the concrete sample is subjected to, resulting in the polyurea coating to get crushed, thereby not being able to contribute to the final load carrying capacity of the concrete sample. On the other hand, a study conducted in 2013 by Mohotti et al. examining the effect of bullet velocity on polyurea-coated aluminum sheets with 7 different thicknesses via the high velocity bullet penetration test revealed that the thicker the polyurea layer the more the bullet's energy, some of which was lost to the aluminum sheet, was damped by the coating. Accordingly, the total energy absorbed by 6 mm polyurea coating was approximately 50% of the energy absorbed by the 12 mm polyurea coating. In other words, the energy dissipated increased with the increase in coating thickness.[37] The discrepancy with the findings of this study and the said study may be attributed to the bending effect of the beam sample in the former and the impact effect of the plate sample in the latter study.

As can be seen in Figure 3b, the deflection amounts increased significantly as the polyurea coating thickness increased in the polyurea-coated concrete samples compared to the reference concrete samples. Nevertheless, the increase in the deflection amounts decreased compared to the reference concrete samples as the polyurea coating thickness increased. Therefore, it has been concluded that increasing the polyurea coating thickness result in less ductile behavior in concrete samples. The energy absorption (toughness) capacities of the concrete samples are given in Figure 3c.

The energy levels of the polyurea-coated samples were noticeably higher compared to the reference samples. However, increasing the thickness of the polyurea coating decreased the toughness capacities as in the deflection amounts. This finding has been attributed to the increase in the embrittlement of the concrete samples as the coating thickness increased.

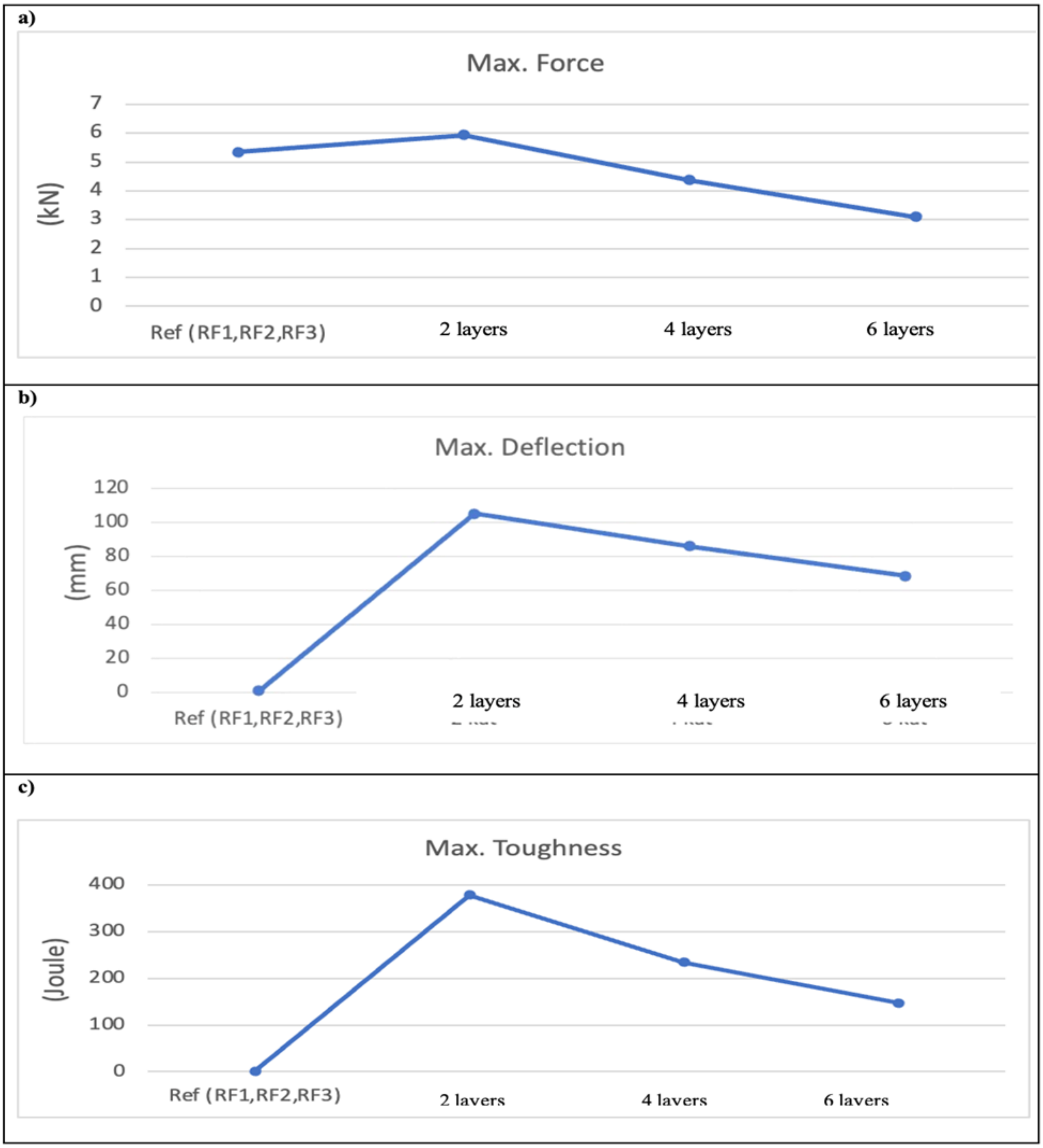

Figure 3 a) Variation of the Force Acting on the Samples. **b)** Variation of the Force Acting on the Samples. **c)** Variation of the Force-Induced Deflections in the Samples.

As a matter of fact, a study (Mohotti et al., 2015) on the effect of high-velocity bullets compliant with the North Atlantic Treaty Organization (NATO) standards on 4 polyurea-coated aluminum plates revealed a significant positive correlation between the thickness of the polyurea coating and the reduction in the residual velocity of the bullet. Consequentially, use of polyurea has been recommended as an additional shield in reducing the velocity of flying fragments.[38] Parniani and Toutanji (2015) investigated the fatigue performance of polyurea-coated reinforced beams compared to uncoated reinforced beams, and found that polyurea-coated reinforced beams were less damaged than the uncoated reinforced beams.[39] Similarly, in a study conducted in 2018, Gauch et al. investigated the strength of the polyurea coating on woven e-glass/epoxy roll-wrapped cylinders subjected to explosives under the water, and found that polyurea coating significantly reduced the damage caused by the explosion on the cylinders compared to uncoated cylinders.[40]

All these findings support the hypothesis that polyurea increases the strength of materials it is coated with in general. In specific, it can be said that the use of polyurea coatings in building elements up to a certain thickness would significantly increase the ductility of the building elements such as steel reinforcements, greatly increasing the deflection amounts, thereby increasing the energy absorption capacity of the structure.

CONCLUSIONS

Risk-based studies against all kinds of disasters in the world and in Turkey have gained great importance in recent years. Regardless of whether it is natural or anthropogenic in origin, an effective intervention can only be possible if the things needed to do in face of a disaster are determined in advance and implemented during the disaster. Earthquakes, which are disasters of natural origin, cause great loss of life and property through the damages they inflict upon the structures. The risks associated with disasters, such as earthquakes, determine the way lives are lost. Along these lines, this study was carried out to reduce the risks associated with the buildings, which are likely to be damaged by earthquakes, by strengthening their structures. Polyurea coating, a potential alternative in reducing vulnerability, has different uses in many areas. However, it has not yet found use in building elements, particularly in undamaged structural elements. In this context, the findings of this study in respect of the reactions exhibited by the unreinforced polyurea-coated building elements against the vertical loads that may occur in the event of an earthquake can provide guidance for future studies.

In the experimental phase of the study, three of the six unreinforced concrete prismatic concrete samples produced in 40x10x10 cm dimensions were coated with 2, 4, and 6 layers of flexible polyurea, respectively. Subsequently, the coated concrete samples, along with the remaining three uncoated unreinforced (reference) concrete samples, were subjected to 3-point bending test in order to comparatively analyze their strengths. Consequently, significant differences were observed in the ductility of the polyurea-coated samples compared to the uncoated reference samples. In addition, the ductility of the sample coated with 2 layers of polyurea was found to be significantly higher compared to the samples coated with 2 and 4 layers of polyurea. In parallel, the sample coated with 6 layers of polyurea had the highest brittleness followed by the samples coated with 4 and 2 layers of polyurea, respectively. This may seem as an unfavorable result in terms of the strength provided by the polyurea coating to the unreinforced concrete building elements at first; however, given the economical aspect of the issue including the cost of the load-bearing elements, it virtually does not have any negative effect on the benefit provided by the polyurea coating. Furthermore, the high fire resistance of the polyurea material will also likely support the building structural system, reducing the overall cost of building construction.

A thorough literature review has shown that polyurea composite material adapts to all kinds of nature and climate conditions, provides high strength, prevents decay, worming and corrosion problems in load-bearing elements, reduces painting, maintenance and renovation costs, ensures energy savings given its high insulation properties, and is resistant to UV and sea effects. Accordingly, coating the building elements with polyurea will not only reduce potential damages to the structures but also provide the structures with high strength (resistance) and durability (resilience) against seismic effects as well as against collapse, storms, fire, etc.

The findings of this study suggest that polyurea coatings can be applied to every structural element of the buildings for purposes of repair and reinforcement against potential earthquake damages for instance as well as for structural maintenance purposes, depending on the extent of the envisaged potential damages (light, medium, heavy).

Declaration of Competing

There are no conflicts of interest to declare.

Data Availability

Data will be made available on request.

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