Investigating the Potential Applications of Elastomeric Polymers (Such as Polyuria and Polyurethane) For ABC and Retrofit

Quarterly Progress Report

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Project Abstract

Elastomeric polymers such as polyurea and polyurethane are nonlinear elastic materials with high tensile strength and strain capacity, adhesiveness, and resistance to permeability and environmental conditions. They have been used commercially as waterproofing and anti-blast coating for reinforced concrete components. While the elastomeric polymer is an interesting material with unique characteristics, there has been limited research on its potential structural applications. A number of research studies have shown the remarkable increase in flexural and shear strength of polyurea-coated reinforced concrete beams. However, further research is needed to explore the application of the polyurea coating system as a new structural material in the bridge industry.

This proposal takes the first step of a long-term research vision to examine and investigate the innovative applications of elastomeric polymers and, specifically, polyurea coating in accelerated bridge construction. Our focus is on the application of elastomeric polymer coatings for the design and retrofit of bridge girders. There are three aspects that can be considered for this application: *(i)* enhancing the flexural and shear strength of the beam through the application of a spray coating, *(ii)* enhancing the weather resistivity, which is especially important for side beams, and most importantly, *(iii)* over height vehicle collision impact resistance. This proposal only focuses on the flexural and shear strength of polyurea-coated RC beams. This simple step is taken to start gaining experience and knowledge on this relatively new material and incrementally examine other aspects of the applications and other potential applications through future proposals and other funding opportunities. We plan for an experimental-analytical research effort to develop simple phenomenological material models for the polyurea coating system and to investigate the potential cost vs. benefit of the coating in the design and retrofit of side girders.

Research Plan

1. Statement of Problem

Based on the collective studies in the literature, it can be concluded that polyurea coating system (Figure 1):

- Increases the flexural and shear strength of RC beams and slabs. It also increases the ductility and failure deformation of RC beams and slabs (which adds to the structural safety by providing alarming deformations before failure) (e.g., [1], [2], [3]),
- Provides waterproofing and environmental resistance to RC surfaces and has good resistance to deteriorating environmental conditions (e.g., freeze-thaw and deicing agents),
- Provides a remarkable local energy dissipation capacity, due to the deformation-induced glass transition of the material, which can enhance the impact resistance of members,
- Is easy to apply (spray coating), dries fast, and has a good bond with the concrete surface, which makes it a solution for on-the-ground as well as in-situ construction and retrofit applications.

Based on the outlined conclusions from the literature, the polyurea coating system is an interesting material with remarkable characteristics that can help to improve the multi-hazard design, construction, and retrofit of accelerated bridge components, with minimum impact on the construction time and site. Figure 2 summarizes the potential applications of the polyurea system in accelerated bridge construction. Despite the significant body of related literature, the practical development of design and construction guidelines requires further experimental and analytical research. This is considering the relatively new introduction of polyurea systems in the structural application and especially the bridge industry.

(a) (b) (c)

Figure 1: Application of polyurea coating (a) masonry slab (photo is taken from [4]*), (b) RC beam specimens (photo is taken from* [3]*), and (c) concrete pipe (photo is taken from* [5]*).*

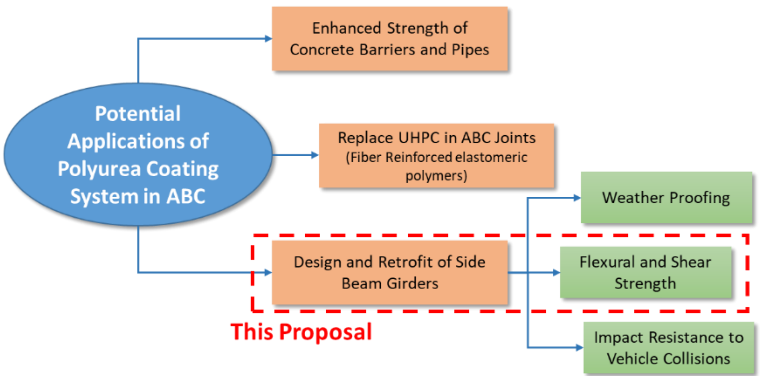

Figure 2: Potential applications of the polyurea system in accelerated bridge construction. This proposal takes the first step of a long-term research vision to examine and investigate the innovative application of the polyurea coating system.

2. Research Approach and Plan

This proposal takes the first step of a long-term research vision to examine and investigate the innovative applications of elastomeric polymers and specifically polyurea coating in accelerated bridge construction. The focus of this proposal is on the application of elastomeric polymer coatings for the design and retrofit of side beams in RC girder bridges. Three aspects can be considered for this application: enhancing the flexural and shear strength of the beam through the application of a spray coating, enhancing the weather resistivity – which is especially important for side beams – and, most importantly, overheight vehicle collision impact resistance. This proposal only focuses on the flexural and shear strength of polyurea-coated RC beams. This simple step is taken to start gaining experience and knowledge on this relatively new material, and incrementally examine other aspects of the applications and other potential applications through a future proposal and other funding opportunities (see Figure 2). The research proposal included 4 tasks as summarized below.

Task 1 – Literature Review

A comprehensive literature review will be performed on the polyurea material and coating system for structural application, including the experimental results, numerical modeling, material models, etc.

Task 2 – Coupon Sample Tests

A series of polyurea coupon samples will be tested under uniaxial cyclic loading scenarios to develop a phenomenological stress-strain and viscosity material model.

Task 3 – Material Model Implementation and FE Numerical Studies

The phenomenological material model will be implemented in a FE simulation platform (e.g., LS DYNA) and will be used to model the response behavior of coated RC beam specimens tested in the literature. The analysis results will be compared with the experimental counterparts provided in the literature to validate the modeling techniques. A model calibration method based on Bayesian inference will be utilized for model calibration and reducing the discrepancies between simulation and experimental results.

Task 4 – Parametric Studies & Economic Analysis

With the calibrated FE model and modeling techniques developed in Task 3, a parametric study will be performed to examine the increase in flexural and shear strength capacity of bridge girder beams due to the polyurea coating. The cost of the polyurea system vs. the increase in strength will be compared with similar solutions (e.g., FRP) to provide an estimate of the economic feasibility of the new material. This step will pave the way to investigate the other potential benefits of polyurea systems for side girder design and retrofit.

3. Time Requirements

The project was planned to be completed in 12 months starting from January 2021 (Table 1).

Table 1: Proposed project timeline.

Year	2021											
Month	1	2	3	4	5	6	7	8	9	10	11	12
Task												
Task 1: Literature Review												
Task 2: Coupon Sample Tests												
Task 3: FE Studies												
Task 4: Parametric Studies												

Percentage of completed work: 30%

Percentage of remaining work: 70%

Progress Report

<u>COVID19-related delays:</u> Due to the Covid-19 pandemic and the closure of U.S. embassies, we could not admit the targeted student researcher that was supposed to join us from the fall semester of 2020 and work on the project. Therefore, the project progress has been delayed for about 5 months (August-December).

We were able to identify and hire a master's student, Pawan Acharya, who has joined our program since January 2021. The updated project timeline would be as follows.

Task 1 – Literature Review: January 2021 – March 2021 (100% completed)

Task 2 – Coupon Sample Tests: March 2021 – April 2021 (50 % completed)

Task 3 – FE Studies: May 2021 – August 2021 (35% completed)

Task 4 – Parametric Studies: September 2021 – December 2021

Task 1 – Literature Review (100% completed)

In the last quarter, we performed an extensive literature review on the polyurea material and coating system for structural application, including the experimental results, material models, and numerical modeling. We attached the summary of the literature review done to this date as an appendix to this report.

Task 2 – Coupon Sample Tests (ongoing – 50% completed)

Polyurea manufacturer and applicator company "Bridge Preservation" supplied us with different polyurea coating samples used in the market. We have acquired the polyurea samples and other required equipment to perform the uniaxial tensile tests on polyurea samples. We performed tensile tests on different types of polyurea to understand their behavior under ASTM standard loading and with varying rates of loading that imitate earthquake loading. Appendix A of this report includes some comparative results of tests performed. We have narrowed the study to a couple of polyurea coatings from various polyurea materials we received. These polyureas were chosen as they show behavior promising for structural application. However, the behavior of the material under cyclic loading is yet to be studied.

Task 3 – FE Studies (ongoing – 35% completed)

We are in the process of developing material models simulating the behavior of the polyurea selected. Moreover, we are developing the analytical models of polyurea applied on RC beams to understand the behavior of the polyurea coated on concrete. Further progress to be reported in the next period.

Appendix A: Material Testing

A.1. Tensile test of different polyurea material types

The project received six polyurea materials from the polyurea manufacturer and applicator company “Bridge Preservation” for the first stage of testing. Table A- 1 summarizes information on Specimen notation, commercial name, and received polyurea sheet thickness. We received a 1ft by 1ft square sheet for each polyurea material.

Table A- 1:List of polyurea materials, their notation, and commercial names

SN	Specimen notation (S#)	Commercial Name	Received Polyurea Sheet thickness
a.	S1	AroStruct	5 mm
b.	S2	AroStruct with fibers	6 mm
c.	S3	Bridge Deck membrane	2 mm
d.	S4	Bridge Deck Membrane Topcoat	2 mm
e.	S5	AquaVers	2 mm
f.	S6	SL75	4 mm

Coupons samples of two sizes, ASTM D638 Die Type 1 and ASTM D638 Die Type 4, were prepared from the polyurea sheets. As S1 and S2 materials were hard and brittle, we used water jet cutting to fabricate the coupons. However, other material sheets were cut with a manual 1-ton arbor press and dies. The arbor press and the dies used in coupon preparation are shown in Figure A 1. Figure A 2 shows the coupon samples cut for the tensile tests performed so far. The general test setup of the tensile test can be seen in Figure A 3. Table A- 2 shows information about the total number of tensile tests performed so far.

Table A- 2:Summary of total tensile test performed

(A) Number of Polyurea material types	= 6	S1,S2,S3,S4,S5, and S6
(B) Number of coupons on each polyurea	= 8	No. of coupons for both dies included
(C) Total number of tensile tests performed	= 48	(C) = (A)×(B)

The thickness of the coupons was nonuniform. So we measured the coupons at three different positions using calipers and calculated the average thickness. Then, when the polyurea coupon was clamped on the Instron Machine, the spacing between the grips was gauged using a scale. Finally, the coupon samples were tested under standard loading rates using Instron Universal Testing Machine. Standard loading rates used for each polyurea material are shown in Table A- 3.

Table A- 3: Standard Loading rates used for tensile tests of different polyurea materials

SN	Specimen	Loading rate used (in/min)	Average coupon thickness
a.	S1	0.2	5 mm
b.	S2	0.2	6 mm

c.	S3	5	2 mm
d.	S4	5	2 mm
e.	S5	5	2 mm
f.	S6	10	4 mm

Figure A 1: (a) Arbor press (left) (b) ASTM Standard Die 1 (top) and Die 4 (bottom)

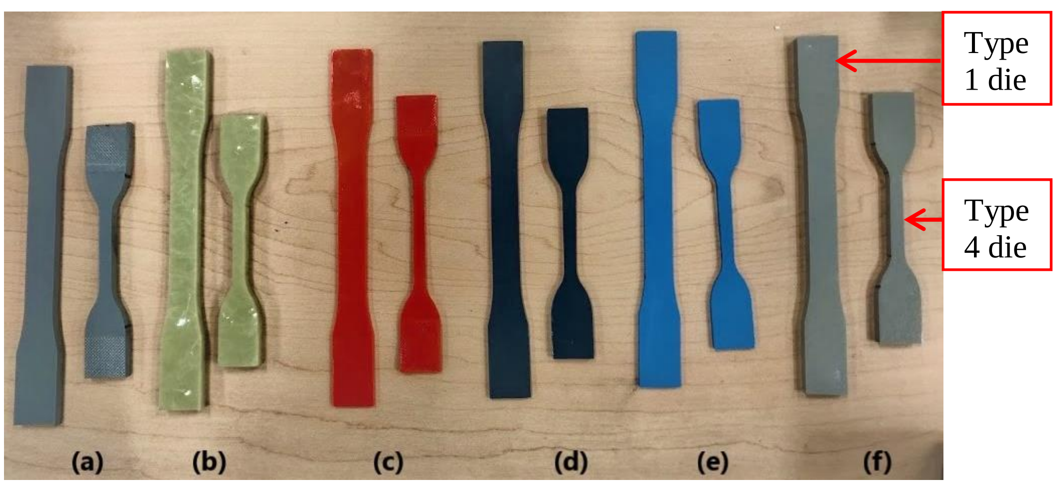

Figure A 2: Coupon samples of Polyurea materials (a) AroStruct (b) AroStruct with fibers (c)Bridge Deck membrane (d) Bridge Deck Membrane Topcoat (e) AquaVers (f) SL75

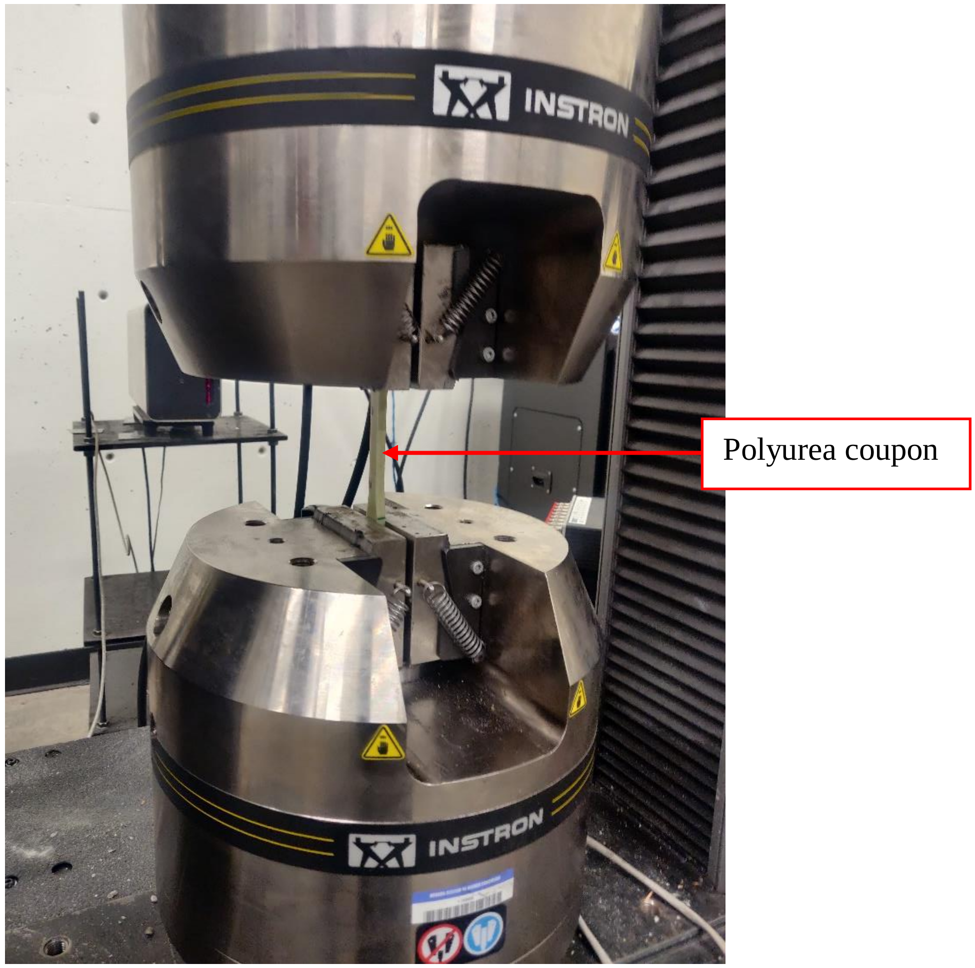

Figure A 3: Test Setup using Instron Universal Testing Machine

The Instron machine recorded load and displacement data of the tensile test. Stress values were calculated in pounds per square inch by dividing the obtained load with the original cross-section of the coupon at the narrow region. Strain values were calculated as a percentage by dividing displacement recorded with the initial spacing of the Instron grips. We processed the data in terms of stress and strain to account for the thickness variation of different polyurea materials and the difference in grip spacing for different coupons.

Figure A 4 and Figure A 5 show the stress-strain plots obtained by averaging the results of several tests performed for ASTM D638 Type 1 die and Type 4 die, respectively, of different polyurea materials.

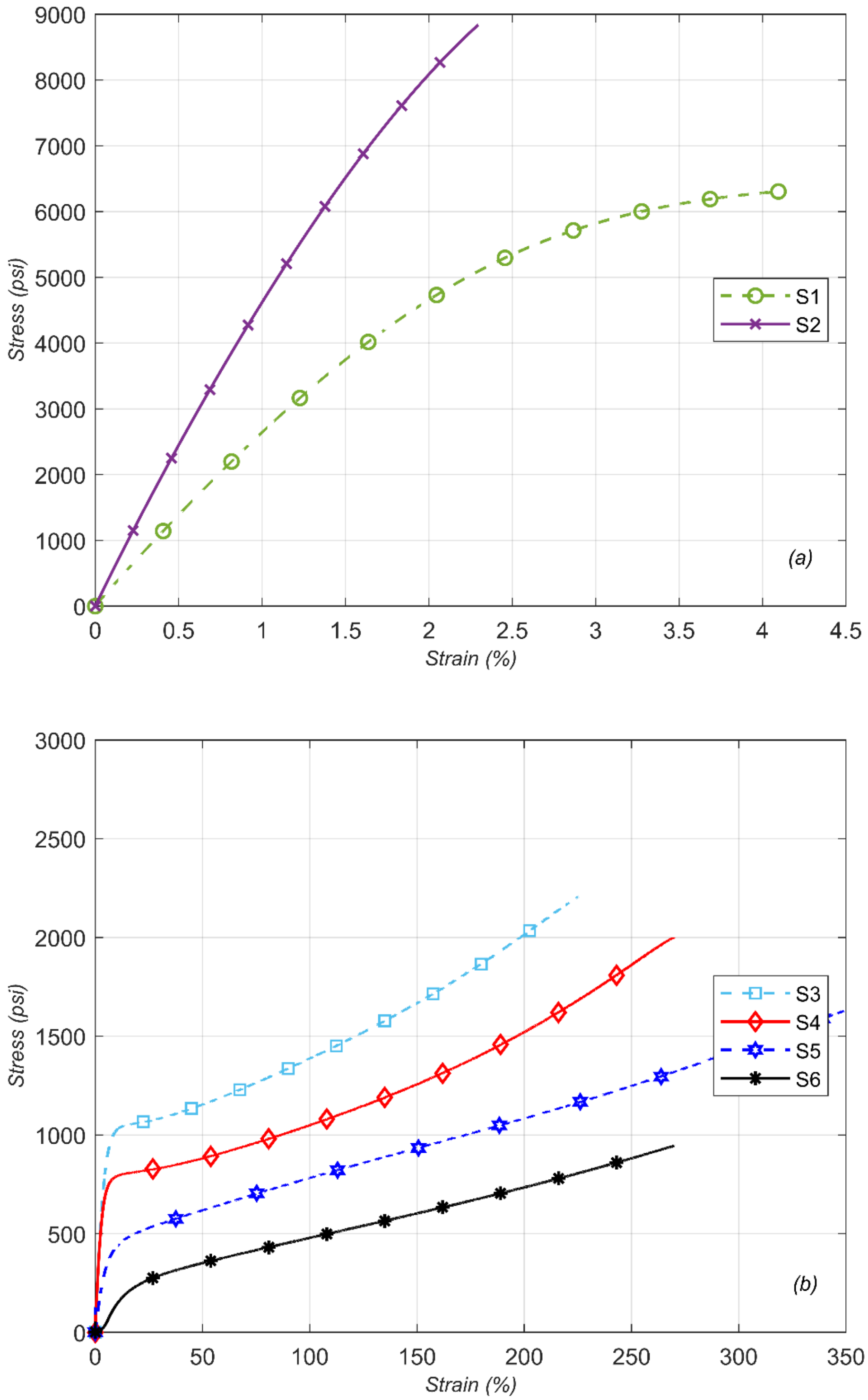

Figure A 4: Average stress-strain curves of Type 1 die coupons of (top) S1 and S2 polyurea materials (bottom) S3, S4, S5, and S6 polyurea materials

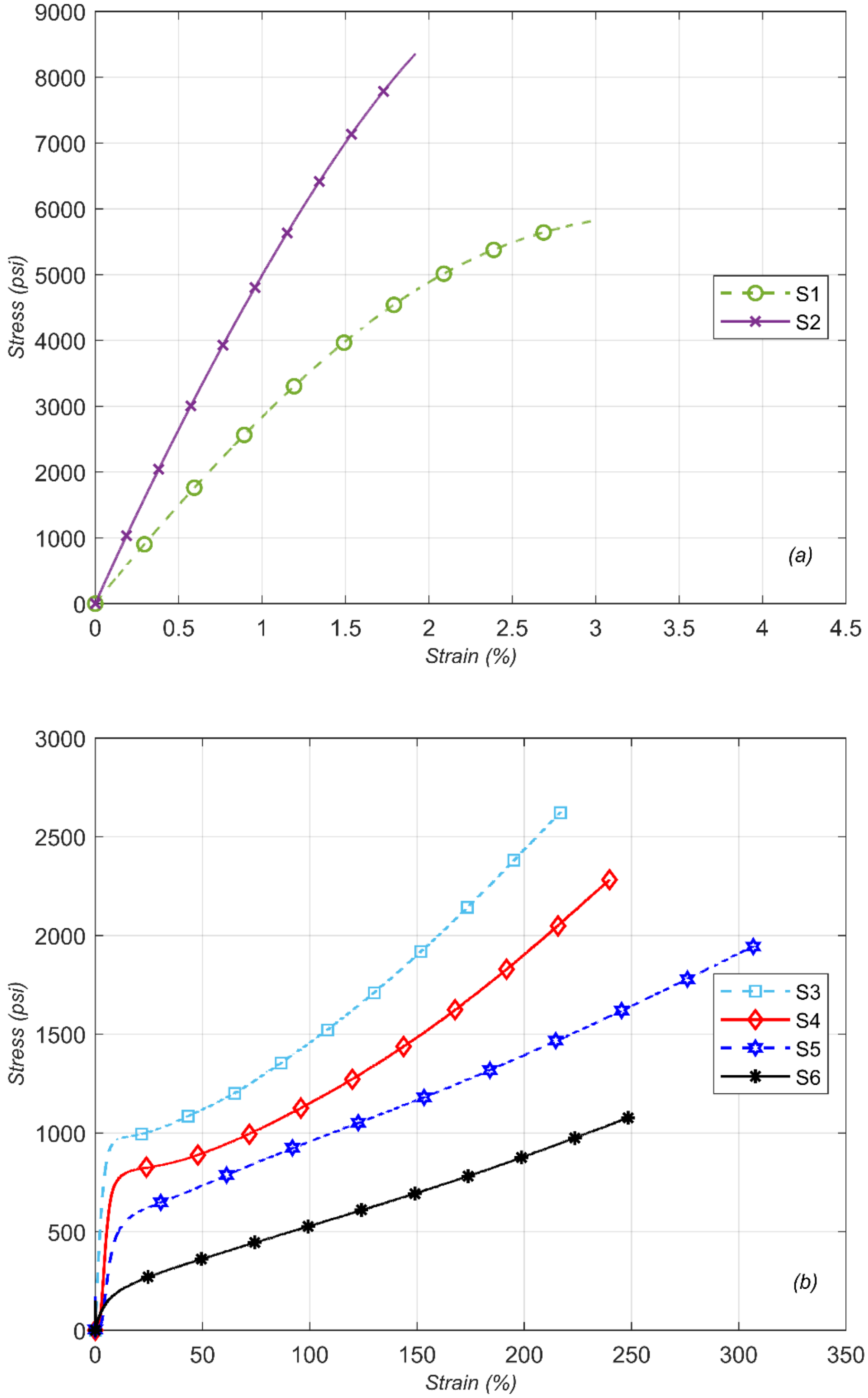

Figure A 5:Average stress-strain curves of Type 4 die coupons of (top) S1 and S2 polyurea materials (bottom) S3, S4, S5, and S6 polyurea materials

As can be observed, all polyurea materials show nonlinear behavior. For S1 and S2 materials, the nonlinearity is subtle compared to S3, S4, S5, and S6 materials. The highly nonlinear behavior of S3, S4, S5, and S6 materials is evident from the results shown in Figure A 4(b) and Figure A 5(b). Figure A 4(a) and Figure A 5(a) show that S1 and S2 materials rupture at low strains less than 5%. We could observe slight yielding of S1 and S2 material slightly before they break. We see large elongations in S3, S4, S5, and S6 materials before rupture. S3 and S4 materials showed hardening behavior after they have yielded. S5 and S6 materials show that they follow linear regimes at a lowered stiffness after yielding as the stress-strain plot is nearly straight.

Table A- 4 shows the yield strength, initial tangent stiffness, rupture strength, and strain at rupture for different polyurea materials.

Table A- 4: Yield strength, initial tangent stiffness, and strain at rupture for different polyurea materials for two die sizes

Polyurea Material	ASTM D638 Die type	Yield strength (psi)	Initial stiffness (psi)	Rupture strength (psi)	Strain at rupture (%)
S1	Die Type 1	~6200	~280000	6200	4.2
	Die Type 4	~5900	~290000	5900	3.0
S2	Die Type 1	~8900	~490000	8900	1.8
	Die Type 4	~8400	~540000	8400	1.8
S3	Die Type 1	~800	~20000	2200	>250
	Die Type 4	~800	~18000	2700	225
S4	Die Type 1	~750	~16000	2000	>275
	Die Type 4	~750	~16000	2400	240
S5	Die Type 1	~500	~7000	2000	>370
	Die Type 4	~500	~7000	1950	310
S6	Die Type 1	~250	~1000	950	300
	Die Type 4	~250	~1000	1100	250

As observed from the stress-strain plots in Figure A 4 and Figure A 5, S1 and S2 materials have higher stiffness and strength but lower ductility than S3, S4, S5, and S6 materials for both die sizes. In addition, the results from the tensile tests indicate that S1 and S2 materials have more favorable mechanical properties for structural application than other materials.

References

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