Slime filled pressurized actuators: Reducing leakage by 400,000 times

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***Abstract*— Pneumatic and hydraulic actuators are vulnerable to rupture, micro-cracks, piercing, and tears [1], [2]. Self healing can repair a damaged actuator's pressure vessel. Different approaches focus on the chemical properties or composition of the pressure vessel [1], [2], [3], [4], or its working fluid [5]. However, these actuators rely on restoration of the air-tightness of their pressure vessel, requiring a safe environment, limiting suitable vessel materials, and needing careful fabrication. We propose inflatable actuators be filled with a viscous, shear thickening fluid (slime) so the pressure vessel does not have to be air-tight to function as an effective actuator.**

Here slimes were made of simple ingredients (PVA glue, water, baking soda, shaving cream, and contact lens cleaning solution) [6]. Three variants (Table I) with increasing viscosity were made by increasing the weight percentage of the contact lens solution. Their leakage rates through a 0.4 mm thick 100 % cotton fabric were compared to those of air and water when pressurized at 550 kPa. We also tested the effect of the slimes' high viscosity on extending a 5 cm^3 syringe when pressurized via a length of 5.5 mm inside diameter tubing.

Figure 1 shows the leakage rate of Slime-31 was 0.0005 %/s compared to the 200 %/s of air. The average syringe extension rate at a pressure of 50 kPa with air and water was 0.005-0.009 m/s compared to 4×10^{-5} m/s for Slime-31 with a pressure of 150 kPa (Figure 2). Measurements of the syringe plunger force compared to the force it should produce given its area and the pressure applied yielded force efficiencies for the fluids. A force efficiency of 41-46 % for air and water was noted. The slime's force efficiency ranged from 5 % for Slime-31 to an average of 29 % for Slime-21.

Our results confirm that slimes reduce leakage rates by up to 400,000 times with the compromise of a corresponding reduction in speed by 225 times and a reduction in force efficiency of 9 times. Further, there is a trend in decreasing leakage rate, speed, and force efficiency of the slimes as their viscosity increases. Hence, application of slimes to the filling of actuators' pressure vessels requires a trade-off between the relative importance of speed, efficiency, and leak resilience. Further, slimes' viscous nature raises the challenge of how they can be quickly and efficiently pumped. This motivates future research on their use in soft robotics.

TABLE I: Mixture percentage weight ratios of the slimes.

Slime	PVA glue (%)	Water (20 °C) (%)	Baking soda (%)	Shaving cream (%)	Contact lens solution (%)
Slime-21	43.0	17.2	1.7	17.2	20.8
Slime-26	40.1	16.0	1.6	16.0	26.2
Slime-31	37.5	15.0	1.5	15.0	30.9

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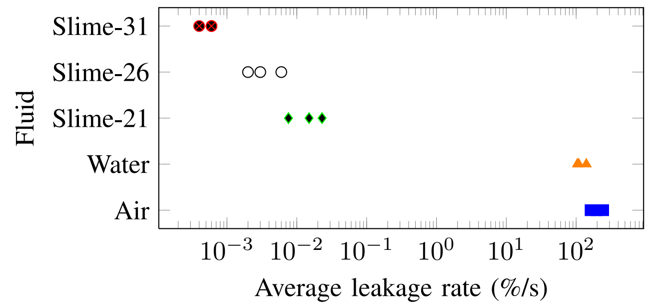

Fig. 1: The average leakage rate of the fluids when pressurized at 550 kPa.

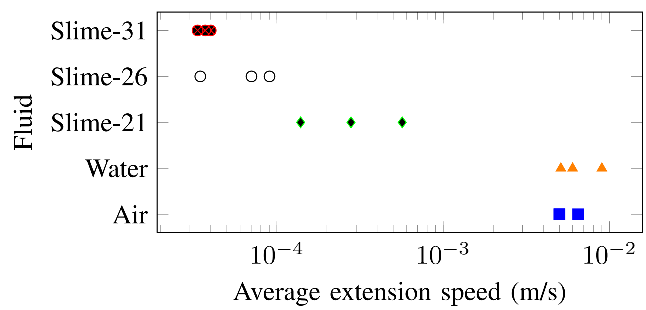

Fig. 2: The average extension speeds of a syringe actuated by the fluids at pressures of 50 kPa (air and water), 100 kPa (Slime-21), and 150 kPa (Slime-26 and Slime-31).

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