Capturing the Age-Dependent Properties of Human Skin Using Variable Stiffness "Smart" Skins

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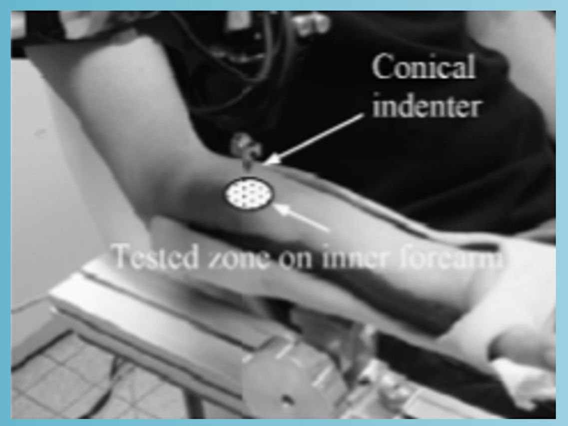
Introduction

Skin is a wildly variable organ, its properties dependent on factors such as age. This research aims to construct a single artificial skin model capable of simulating the full range of age-dependent variability.

Age-Dependent Skin Properties

- To investigate the age dependence of skin modulus, *in-vivo* indentation data is used [1]
- As the age increase, the skin stiffness decreases and the damping increases (see Figure 1R)



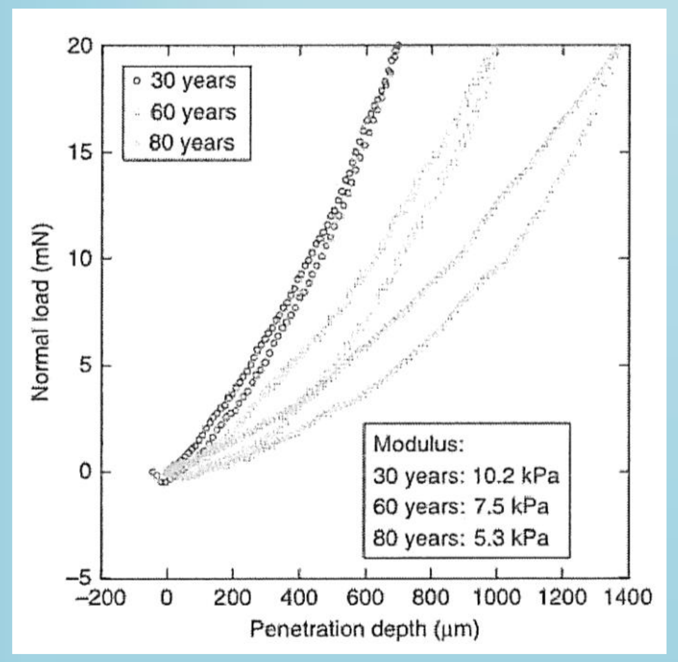


Figure 1 :
(Left): Indentation testing on human forearm [1]
(Right): *In-vivo* indentation testing based on age and modulus [1]

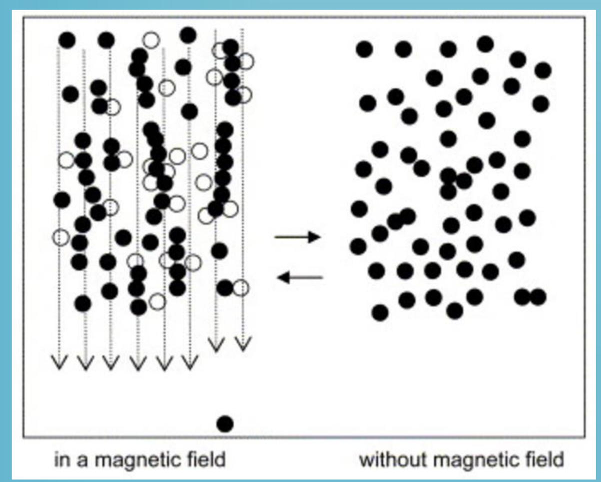
Objective of the Study

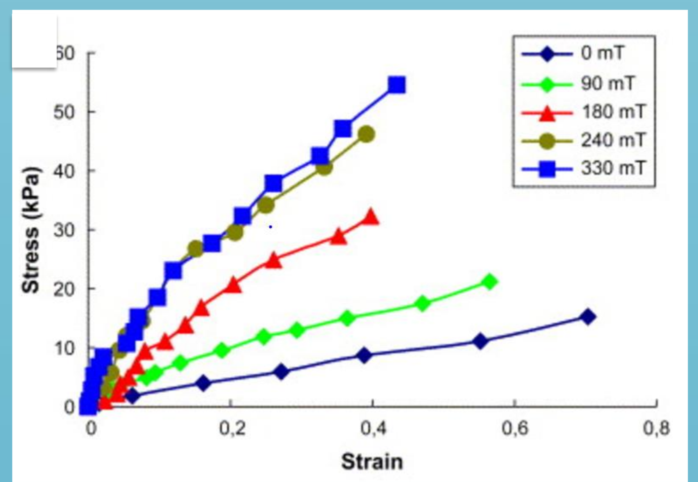
This research will use indentation testing to experimentally test the fabricated samples in order to compare and replicate the *in-vivo* results. More specifically,

- Investigating the biomechanical skin mimicking potential of magnetorheological elastomers (MREs).
- Determining a single MRE sample that is capable of characterizing a wide range of skin properties.

Magnetorheological Elastomers (MRE)

- MRE materials are fabricated using an elastomer base compound embedded with iron particles.
- When a magnetic field is applied perpendicular to the MRE sample, the iron particles align and crosslink, which increases their modulus.





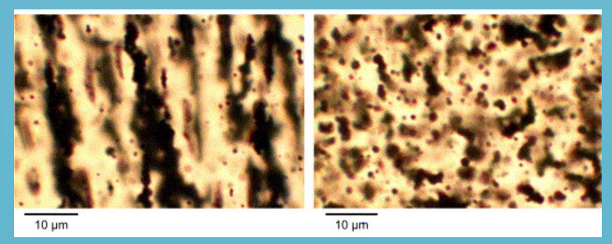


Figure 2:
(Top Left): Illustration of particle behaviors with and without a magnetic field [2]
(Left): Microscopic picture of MREs under field and no field [2]
(Above): Graph showing how stress and strain change as applied field changes [2]

Methodology

Sample Fabrication

- Dermal samples fabricated from a base polymer (EcoFlex) and iron particles were mixed in, and the sample was allowed to cure.
- Thickness and iron content of samples were varied in order to find the most accurate mixture.

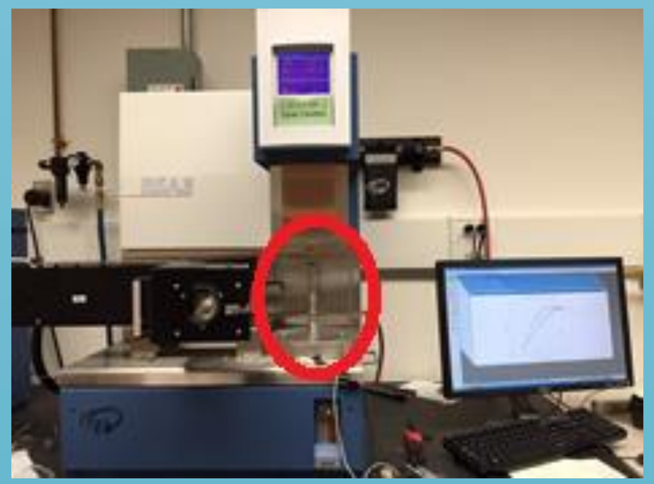
Figure 3:
(Right) Picture of various MRE samples
(Left) Set-up of a sample curing apparatus

- These samples are made to replicate the complexity of human skin. Many variables were investigated, such as magnetic field strength, iron concentration, and multiple layers.

Figure 4:
A diagram indicating human skin structure, and the proposed MRE artificial skin model.

Indentation Testing

- Testing is conducted on a Dynamic Mechanical Analyzer, a machine that measures small variances in stress and strain as a sample is pressed upon.
- The standard indentation head and staging platform are metal, but since these tests would use magnetic fields, alternatives had to be constructed.
- From these graphs, a rough estimate of the stiffness was found by finding the best-fit line, and treating this slope as the modulus.
  - The modulus represents a material's resistance to being deformed, a good estimator for stiffness.



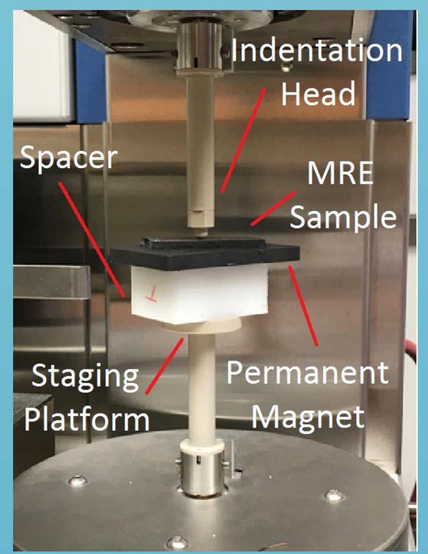


Figure 5:
(Left): The DMA machine housed in the MME department
(Right): Zoomed image of indenter set-up

Experimental Results

Iron Particle Concentration

- Figure 5 shows that as the iron content increases in the MRE sample under a set field (55 mT), the modulus increases, and the loss factor also increases.

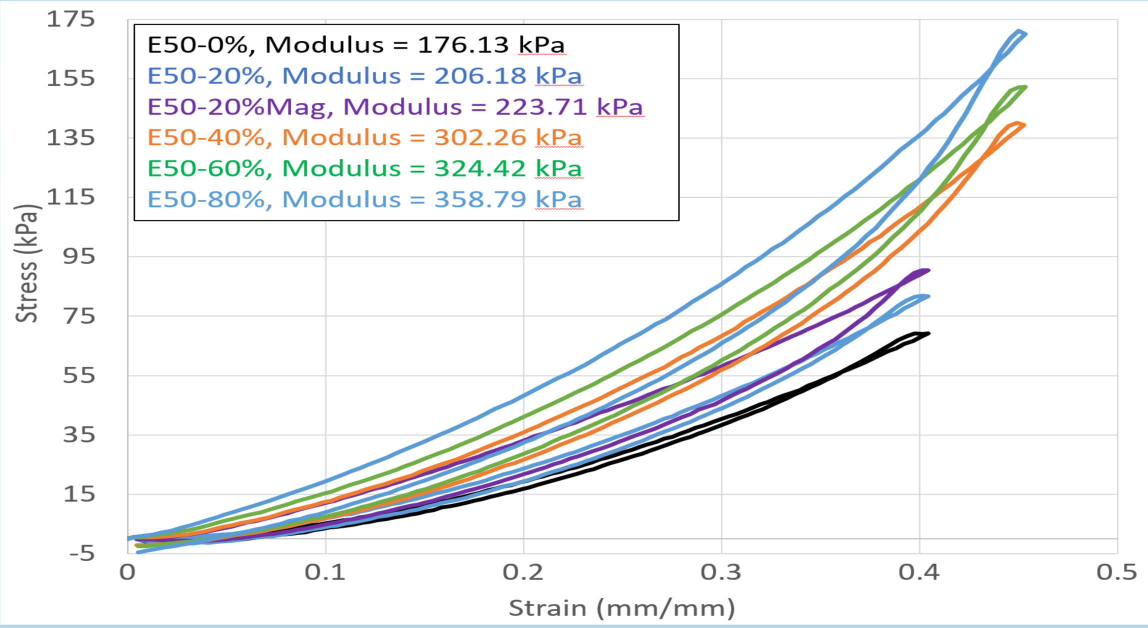


Figure 5:
55 mT Iron Content Comparative Graph, iron concentration varied in test samples

Strength of Magnetic Field

- The literature shows that as field increases, modulus increases, but this was not the trend seen in Figure 6.

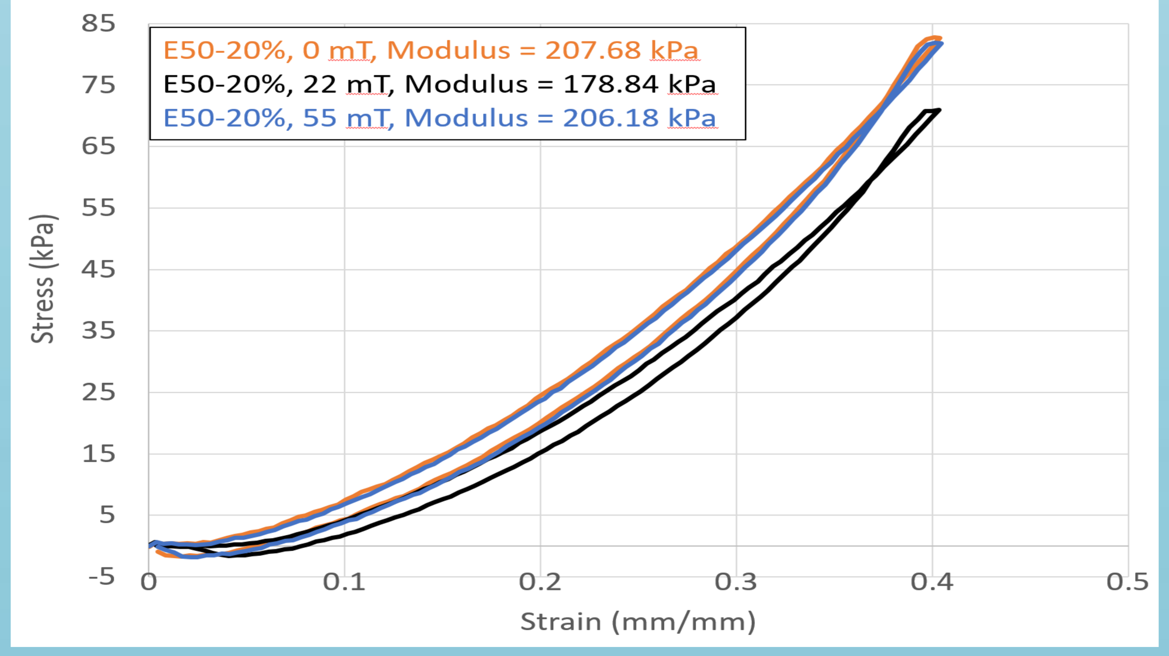


Figure 6:
E50-20 iron% Field Comparative Graph, field strength varied between tests

Indentation Speed Effect

- Figure 7 shows that stiffness values converge as indentation speed decreases, there is much more variability with faster indentation tests.

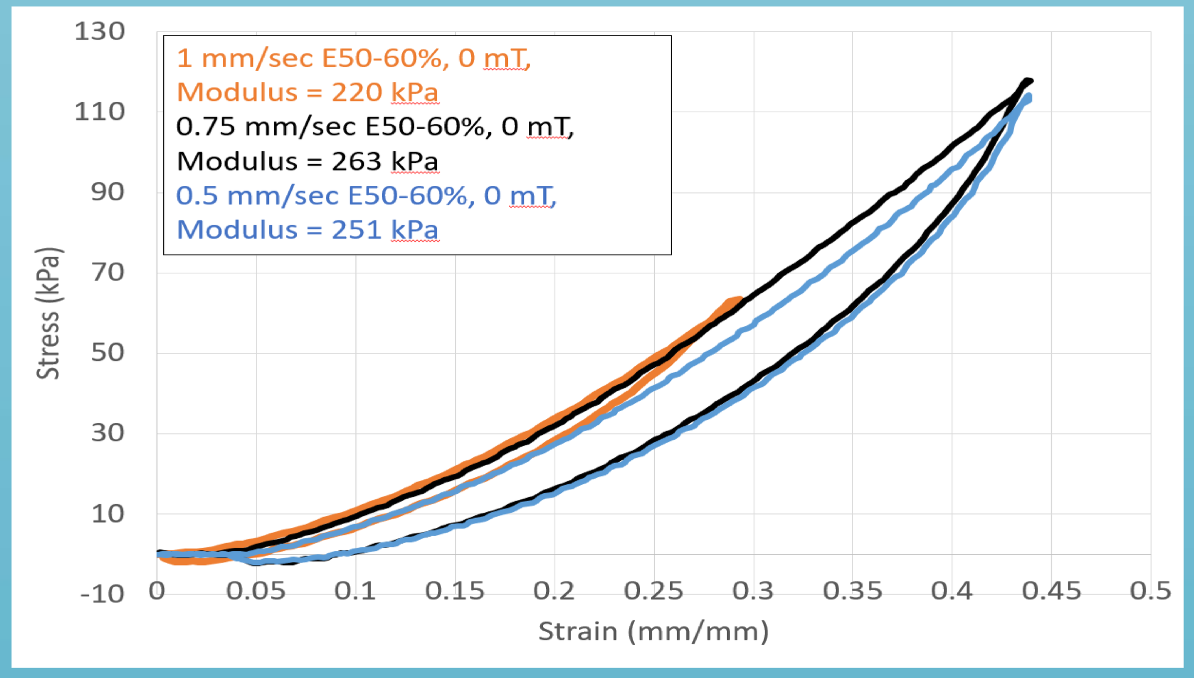


Figure 7:
E50-60% under 0 mT, test to see whether Indentation speed influences modulus

Comparison to *In-Vivo*

- Figure 8 compares the one-layer MRE samples against the in-vivo data based on iron content, indentation speed, and field..

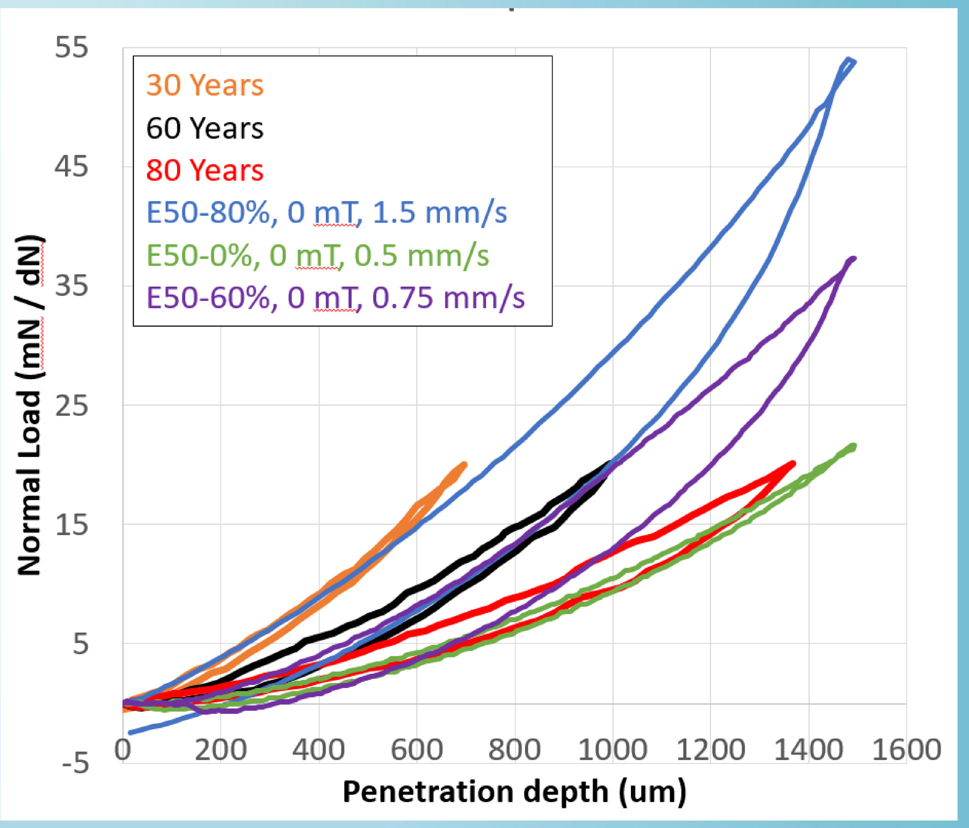


Figure 8:
Comparative graph of experimental data and *in-vivo* data, from [1].

Discussion / Future Work

Two-Layered

- Figure 8 shows that single-layered samples match *in-vivo* modulus data, but damping is very different. Figure 9 shows initial testing of two-layered samples, they allow for more flexibility in choosing iron concentrations, which theoretically allows greater control over modulus manipulation.

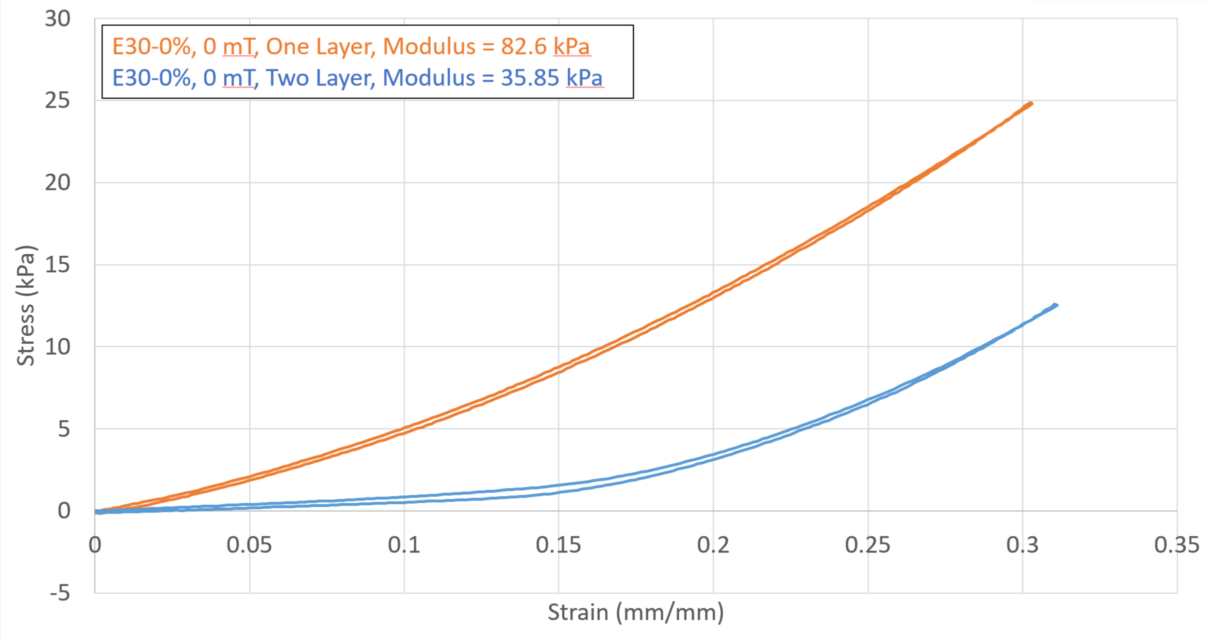


Figure 9:
Two-layer versus One-layer E30-0% samples, tested under the same conditions

- Continue analyzing the unexpected trend. Current theories include that the orientation of the magnetic field is influencing the field.
- Further testing must be done in two-layer samples to try and recreate the in-vivo data with a single model
- Samples will be tested under a greater range of magnetic fields in order to greater see the MRE effect.

References:
[1] Zahouani, H., Pailler-Mattei, C., et. al. (2009). Characterization of the mechanical properties of a dermal equivalent compared with human skin in-vivo by indentation and static friction tests. Skin Research And Technology, 15(1),
[2] Stepanov, G., Abramchuk, S., et. al (2007). Effect of a homogeneous magnetic field on the viscoelastic behavior of magnetic elastomers. Sciencedirect.com.