ELECTRORHEOLOGICAL FLUIDS

Group 1

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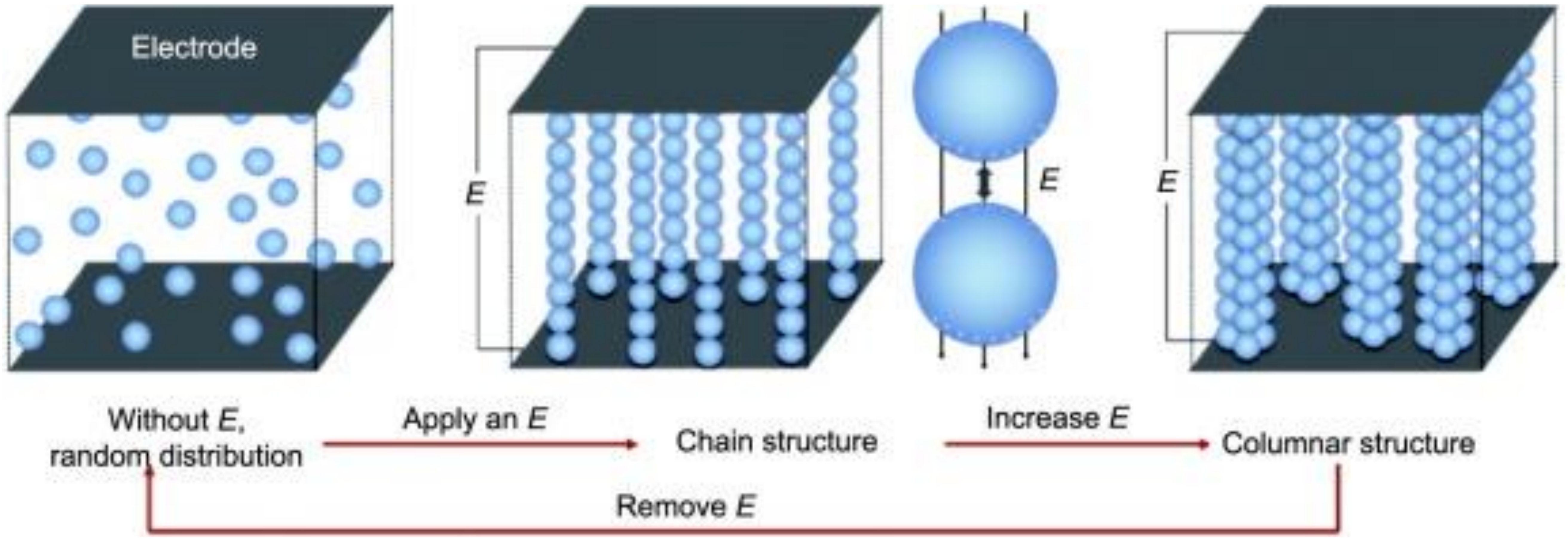
WHAT ARE ELECTRORHEOLOGICAL FLUIDS?

ER FLUIDS



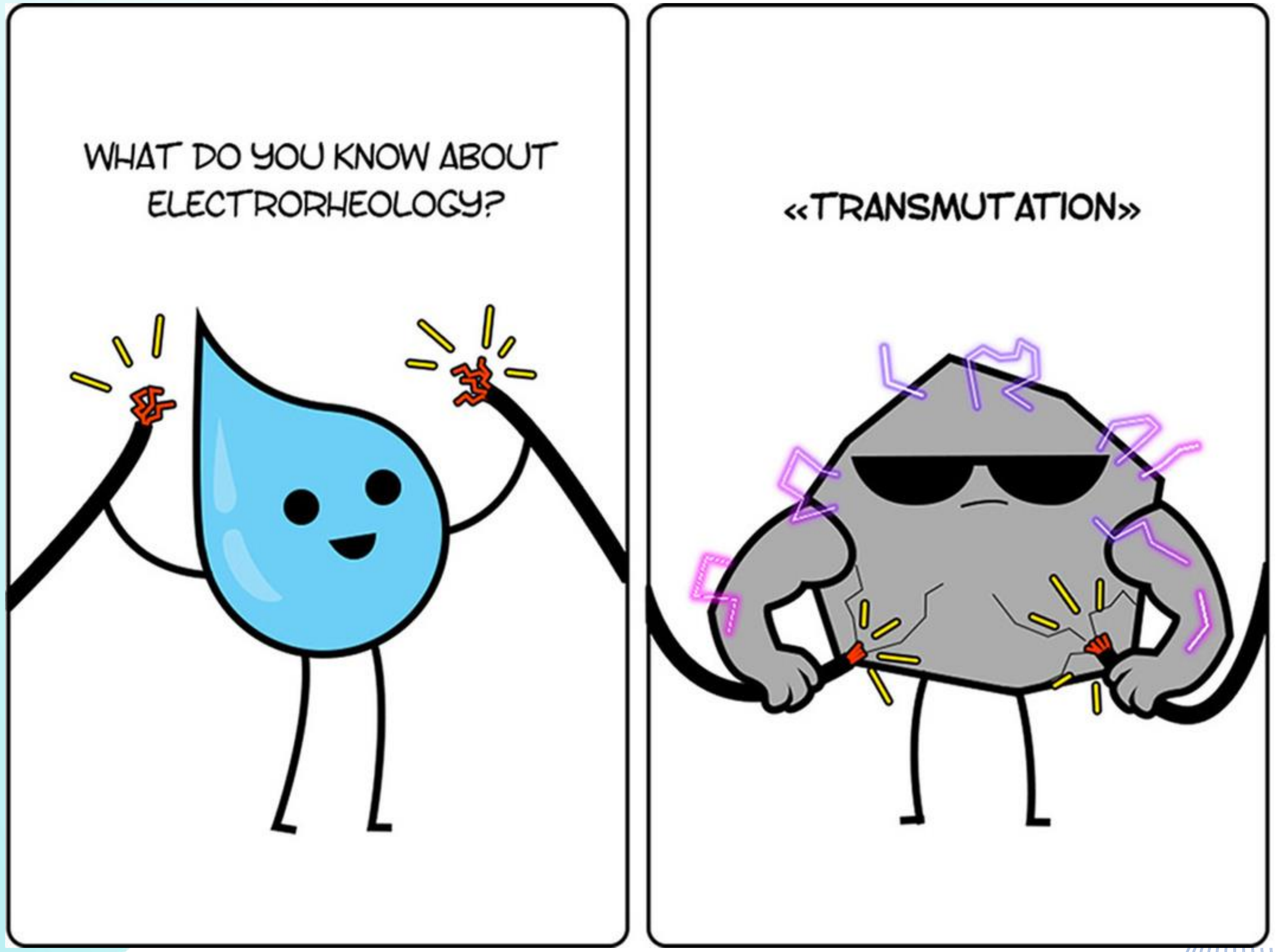
The material starts to exhibit enhanced elastic (Solid-like) behavior. Rheological properties of the fluid change!!

Electrorheological (ER) fluids are dispersions of extremely fine non-conducting but electrically active particles (up to 50 micrometres diameter) in an **electrically insulating fluid** Basically we need dielectric particles in a non-conducting medium.

Water can 't be used as a medium for the dispersion because of its conducting properties !!

Experimental ER fluid: Corn-Starch in Silicon Oil (40wt%)

ER FLUIDS IN AN IMAGE



Electrorheological (ER) fluid

WHY STUDY ER FLUIDS ? AN AMAZING APPLICATION IN ABS (BRAKING SYSTEMS)

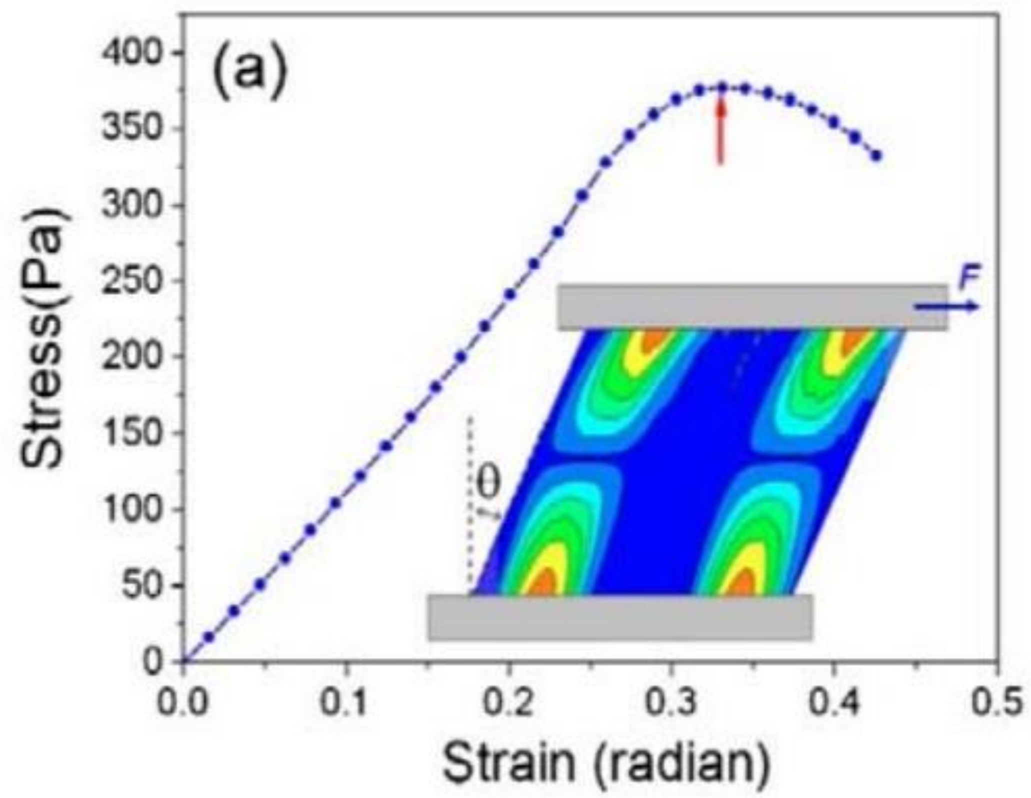


Figure 2. The inset shows the breaking of the columns at around the yield stress point. The static yield stress is 374 Pa [3].

The ER system differs from conventional brakes by converting rotational kinetic energy into bond-breaking (electrostatic interaction) energy, which disrupts the column structures. This electrical-induced process is reversible, as the ER system can rebuild these columns by reapplying an electric field, making it highly durable compared to traditional friction brakes. Additionally, ER systems use high permittivity particles in insulating oil, reducing the risks of fatigue and corrosion associated with friction braking. This prolongs the material's service life and lowers maintenance costs.

Reference paper: https://iopscience.iop.org/article/10.1088/1742-6596/2016/1/012001/pdf#:~:text=periodical%20electric%20field%2C%20the%20ER,maintain%20control%20of%20the%20vehicle.

OBJECTIVES

- **Creep and Recovery Experiment** on ER fluids at varying electric fields
- **Stress Relaxation Experiment** on ER fluids at varying electric fields

EXPERIMENTAL SETUP

Specifications:

Room temperature = 25˚C

PP25/E/T1

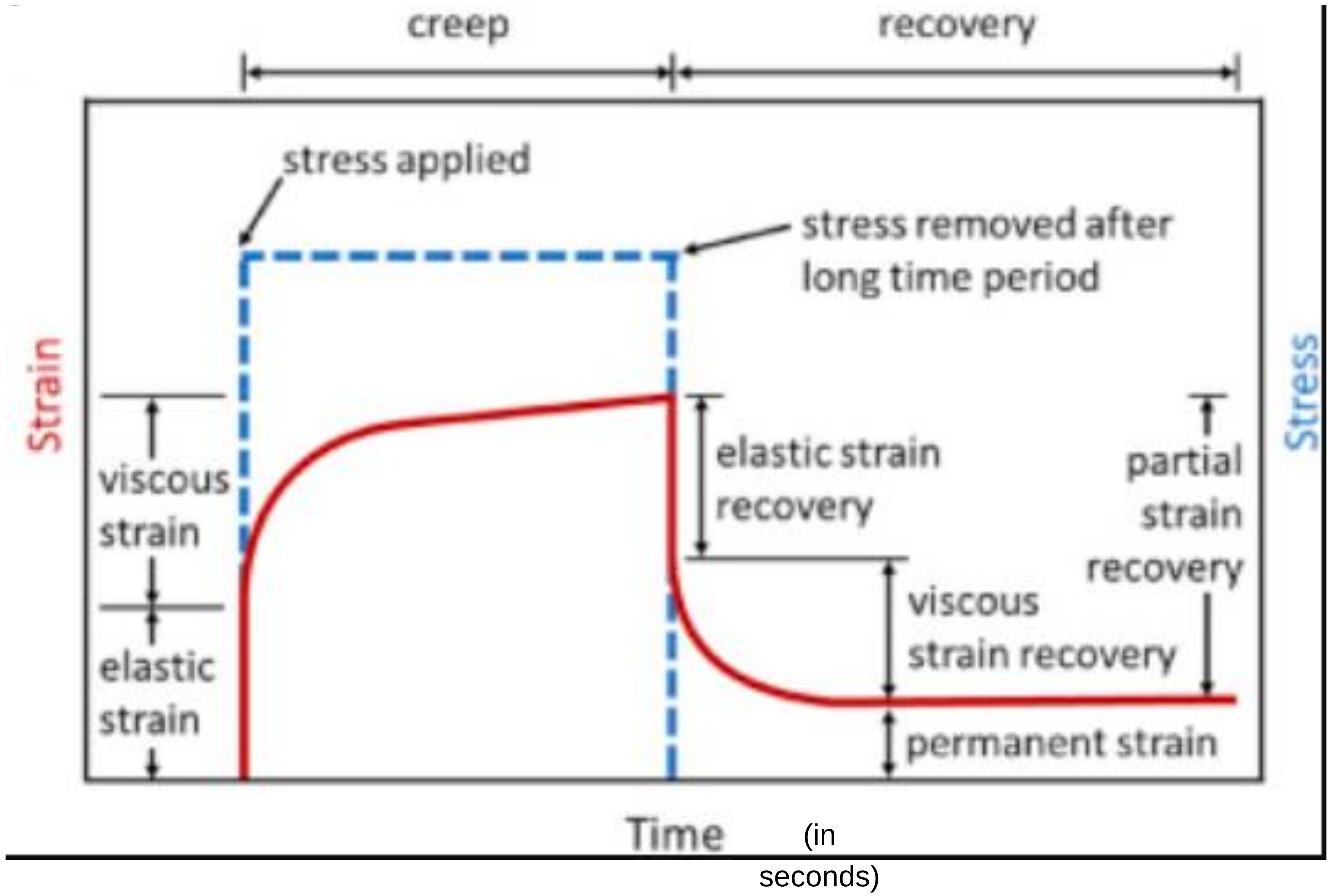
Parallel Plate

Diameter = 25 mm

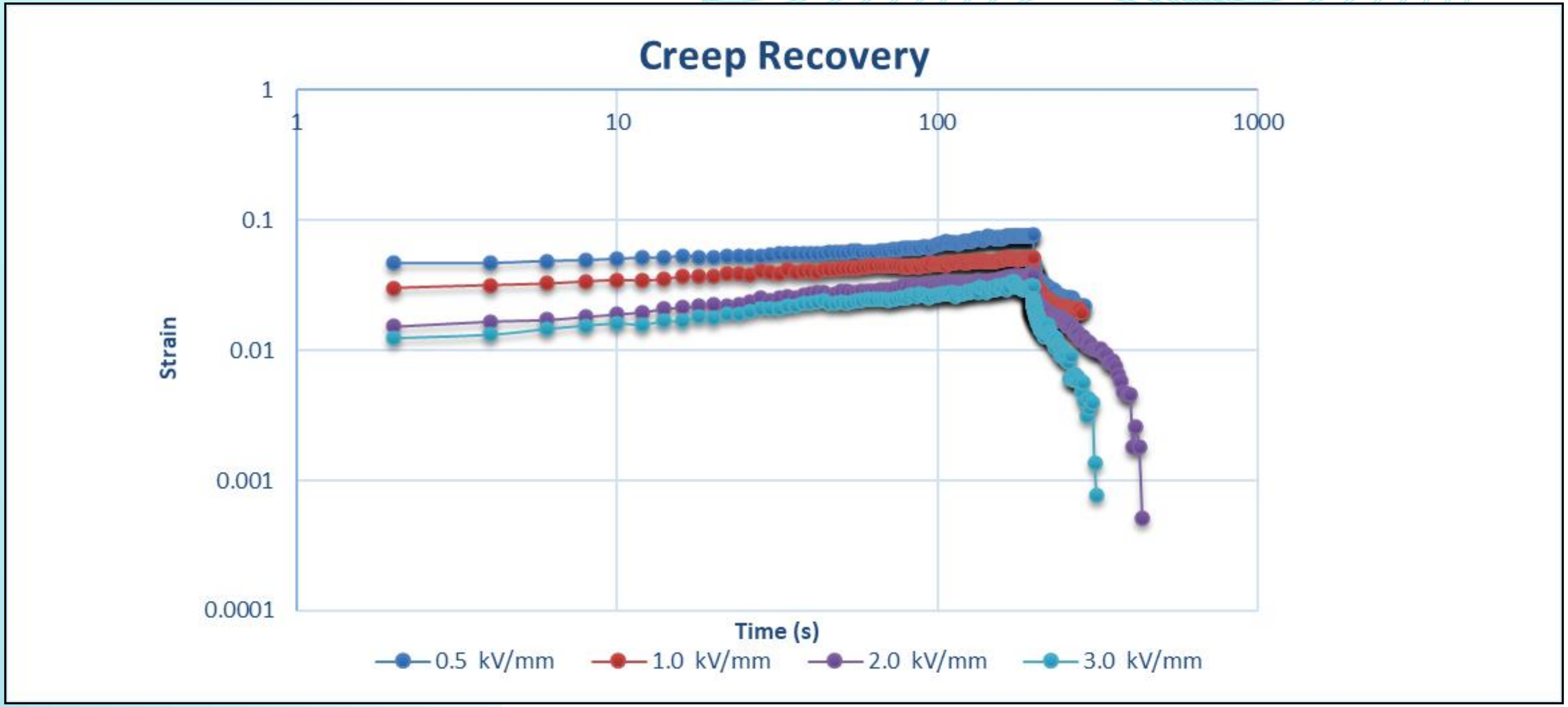
Gap between plates = 1 mm

CREEP AND RECOVERY EXPERIMENTS ON ER FLUIDS AT DIFFERENT E

- When a polymeric (soft) material is subjected to an abrupt step stress, the response can be modeled using the Burger Model
- At a time t=0, a viscoelastic material is loaded with a constant stress that is maintained for a sufficiently long time period.
- The material responds to stress, causing strain to increase until failure. If stress is maintained briefly, strain rises until time t1, when stress is released, resulting in an abrupt strain decrease, followed by gradual reduction to a residual strain.



RESULTS

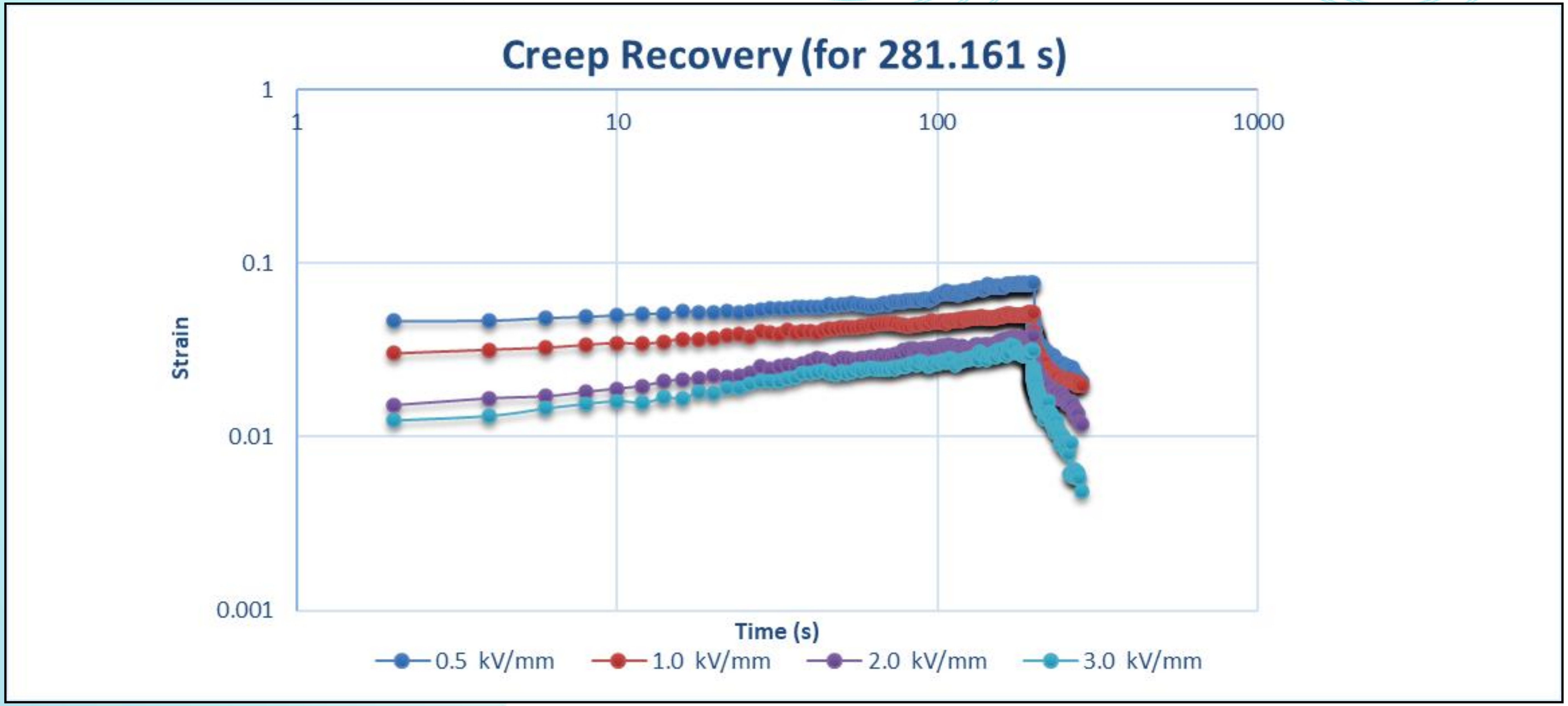


We carry out the Creep Recovery Experiment by providing a Step Stress to the material for 200 seconds, beyond which, we remove the Step Stress causing the material to enter the recovery phase.

The results of Strain v/s Time have been plotted on a log-log scale.

We can notice an increase in strain till the step stress is applied, followed by recovery right after we remove the Step Stress.

ANALYSIS



However, our experiment was not carried out for the same time period for different Electric Fields. (The experiment for 2kV/mm Electric Field was carried out for 436 seconds, while other experiments were around 280+ seconds!).

Hence, for the sake of our analysis, we plotted all the graphs to 281.161 seconds, as it was common for all experiments.

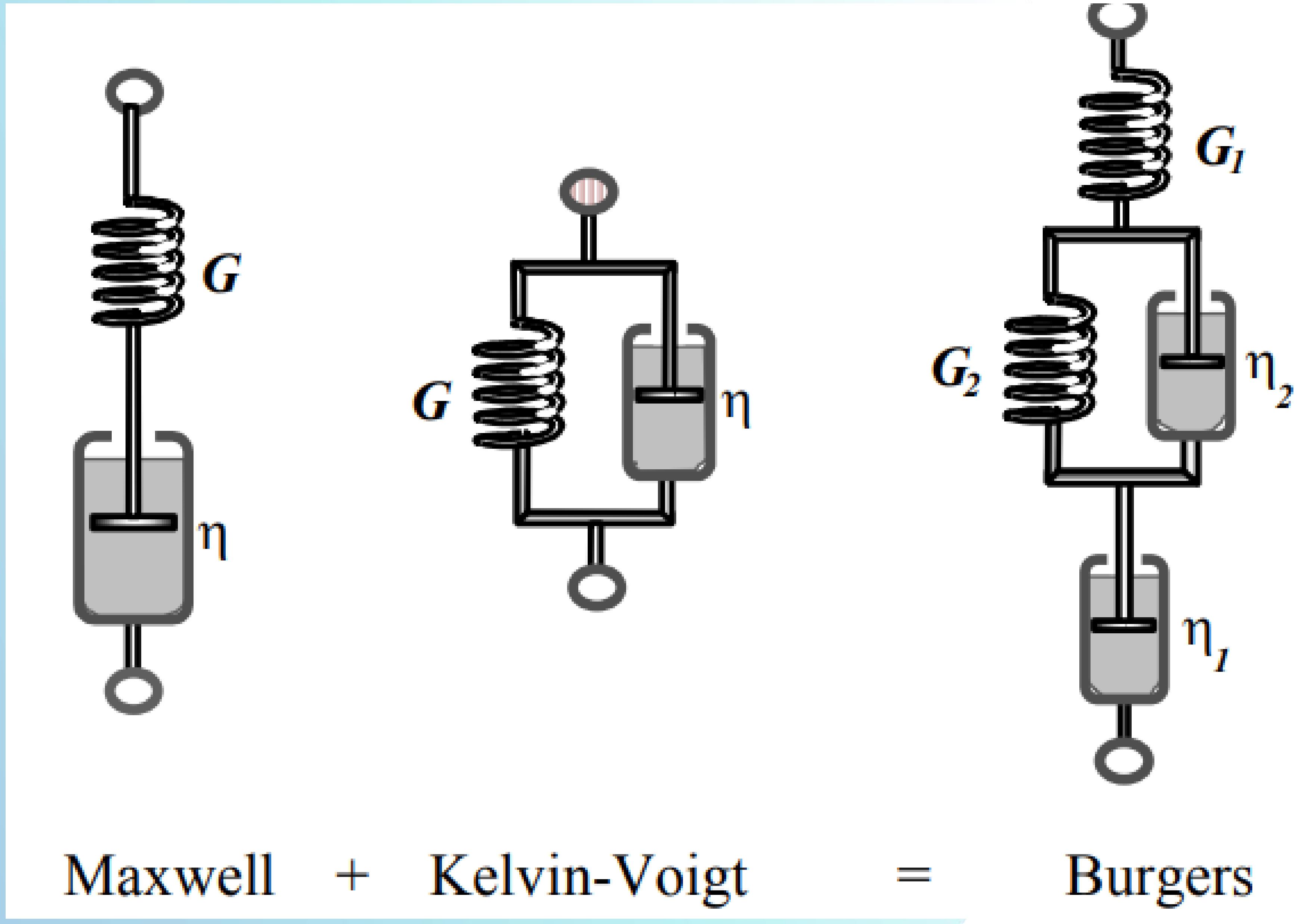
ANALYSIS- CONTINUED

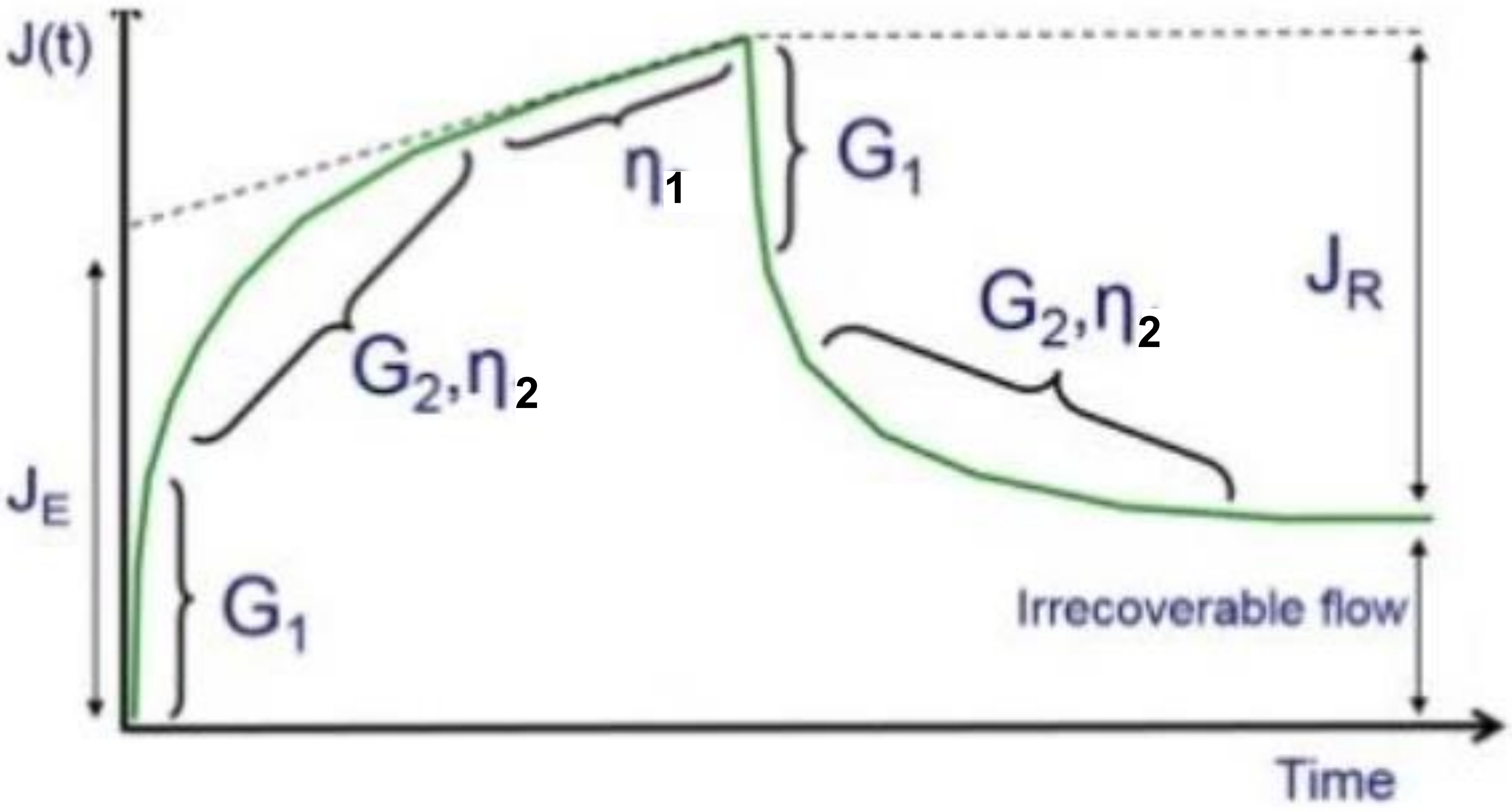
Electric Field (in kV/mm)	Recovery Percentage
0.5	72.80%
1	61.67%
2	69.19%
3	84.68%

Ideally, as the addition of an Electric Field imparts a solid-like nature to the material, we would expect there to be a higher recovery for a greater field.

But, our experimental results fail to show that in the case of 0.5kV/mm. While we cannot find any theoretical justification for it, if we were to explain, we are inclined to believe that there might have been a breaking of physical chains while we were performing the experiment for 1 kV/mm and 2 kV/mm, leading to a more liquid-like behavior, which would lead to a slower recovery.

CREEP AND RECOVERY EXPERIMENTS ON ER FLUIDS AT DIFFERENT E

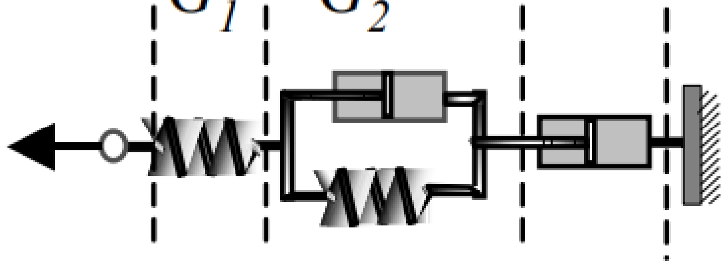




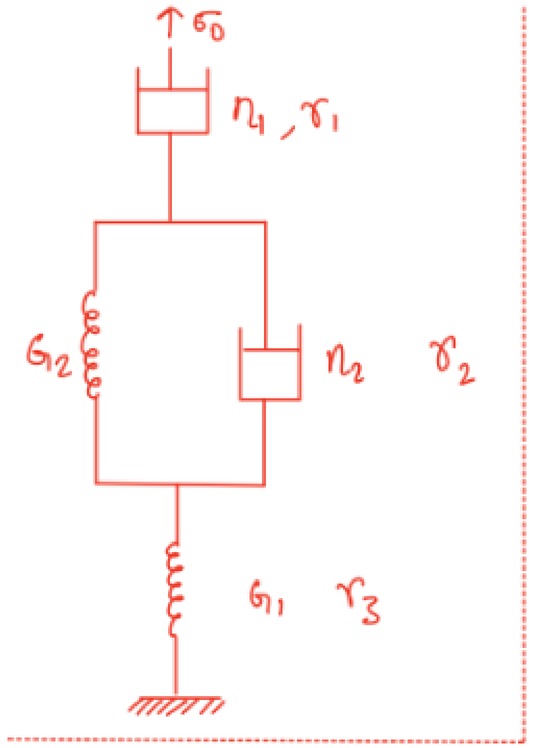
equation

$$\frac{\gamma(t)}{\sigma} = \frac{1}{G_1} + \frac{1}{G_2}\left(1 - e^{t/\lambda}\right) + \frac{t}{\eta_1}$$

model



DERIVING THE BURGER'S MECHANISTIC MODEL



$\rightarrow \quad \sigma_0 = \eta_1 \dot{\gamma}_1 \Rightarrow \dot{\gamma}_1 = \frac{\sigma_0}{\eta_1}$

$\gamma_1 = \frac{\sigma_0}{\eta_1} t + \text{constant}$

$\rightarrow \quad \sigma_0 = G_1 \gamma_3 \Rightarrow \gamma_3 = \frac{\sigma_0}{G_1}$

$\rightarrow \quad \sigma_0 = G_2 \gamma_2 + \eta_2 \dot{\gamma}_2$

$\frac{\sigma_0}{\eta_2} = \frac{\gamma_2}{\tau_2} + \frac{d\gamma_3}{dt}$

$\int_{\gamma_2(0)}^{\gamma_2(t)} \frac{d}{dt}\left(\gamma_2 e^{t/\tau_2}\right) = \frac{\sigma_0}{\eta_2} \int_0^t e^{t/\tau_2}$

$\gamma_2 e^{t/\tau_2} - \frac{\sigma_0}{\eta_2} \times \frac{\eta_2}{\tau_2} \left[e^{t/\tau_2} - 1 \right]$

$\Rightarrow \quad \gamma_2(t) = \frac{\sigma_0}{G_2} \left[1 - e^{-t/\tau_2} \right]$

$$\boxed{\Rightarrow \quad \gamma(t) = \sigma_0 \left[\frac{1}{G_1} + \frac{t}{\eta_1} + \frac{1}{G_2} \left[1 - e^{-t/\tau_2} \right] \right]}$$

$t = t_1 , \quad \sigma_0 \rightarrow 0 , \quad \gamma_3 = 0$

$\rightarrow \quad \gamma = \gamma_1 + \gamma_2 + \cancelto{0}{\gamma_3} \quad , \quad \eta_1 \dot{\gamma}_1 = 0 \Rightarrow \dot{\gamma}_1 = 0$

$\Rightarrow \gamma_1 = \text{constant}$

$\int_{\gamma(t_1)}^{\gamma(t)} \frac{d\gamma}{dt} = 0 \qquad (\gamma(t) = \gamma(t_1))$

not recovered

$\Rightarrow \quad \gamma_1 = \frac{\sigma_0 t_1}{\eta_1}$ (RESIDUAL STRAIN)

$\rightarrow \quad 0 = G_2 \gamma_2 + \eta_2 \dot{\gamma}_2$

$\eta_2 \frac{d\gamma_2}{dt} = -G_2 \gamma_2$

$\int_{\gamma_2(t_1)}^{\gamma_2(t)} \frac{d\gamma_2}{\gamma_2} = -\int_{t_1}^{t} \frac{dt}{\tau_2} \Rightarrow \ln\left(\frac{\gamma_2}{\gamma_{t_1}}\right) = -\frac{(t - t_1)}{\tau_2}$

$\gamma_2 = \gamma_2(t_1)\, e^{-(t-t_1)/\tau_2}$

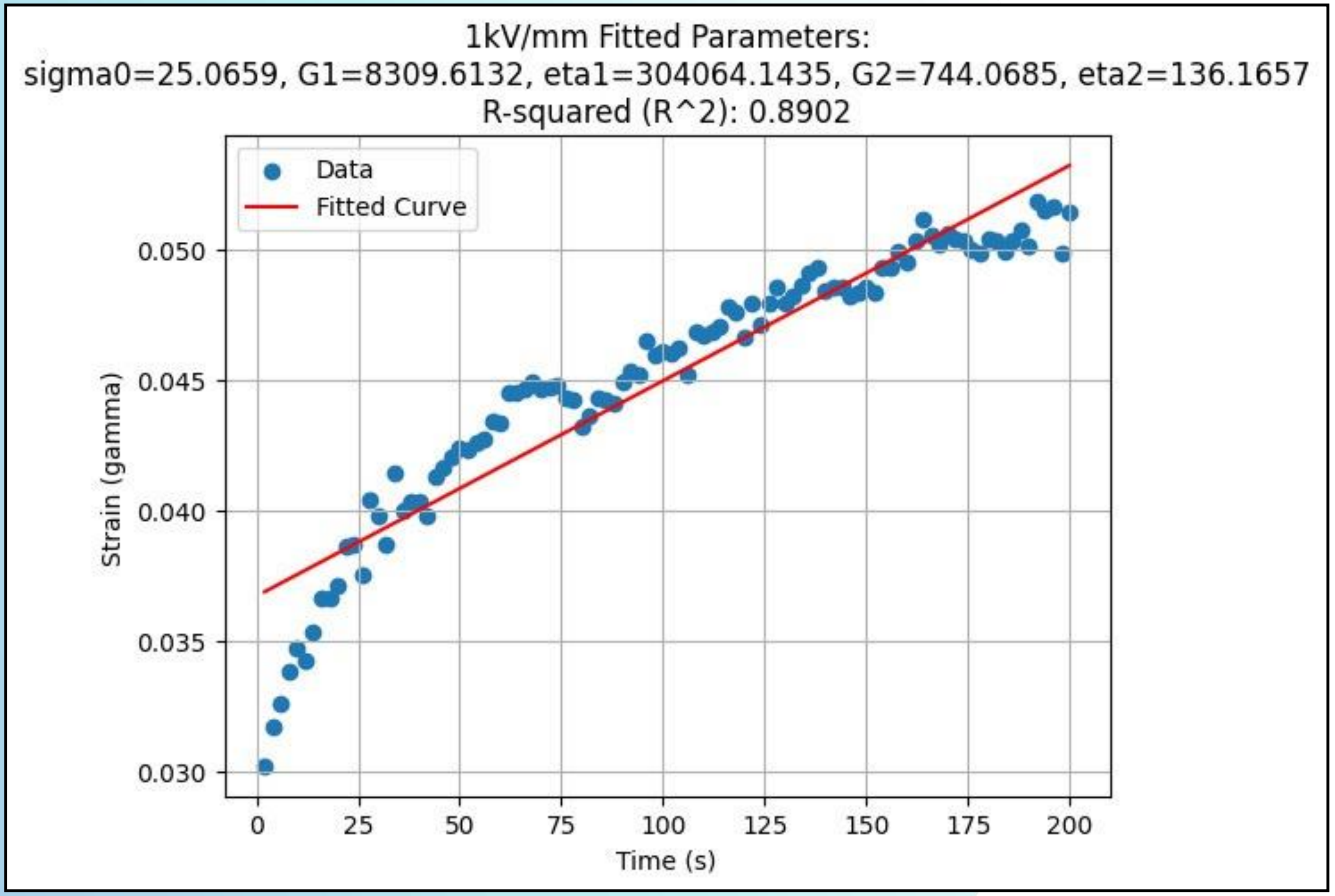
$= \frac{\sigma_0}{G_2} \left[1 - e^{-t_1/\tau_2} \right] e^{-(t-t_1)/\tau_2}$

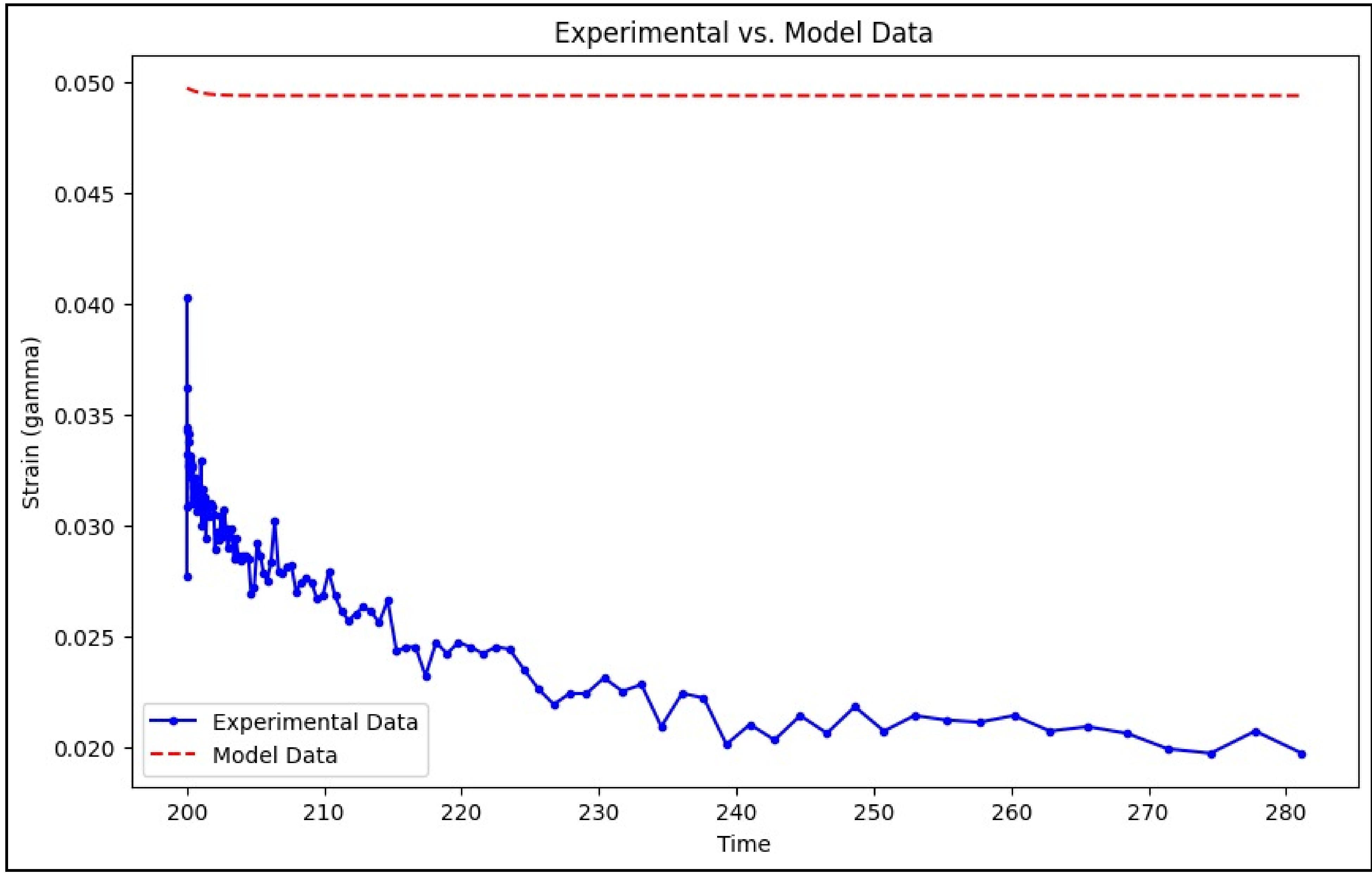
$= \frac{\sigma_0}{G_2} e^{-t/\tau_2} \left[e^{t_1/\tau_2} - 1 \right]$

$\gamma = \gamma_1 + \gamma_2$

$$\boxed{= \sigma_0 \left[\frac{t_1}{\eta_1} + \frac{1}{G_2} e^{-t/\tau_2} \left[e^{t_1/\tau_2} - 1 \right] \right]}$$

CURVE-FITTING

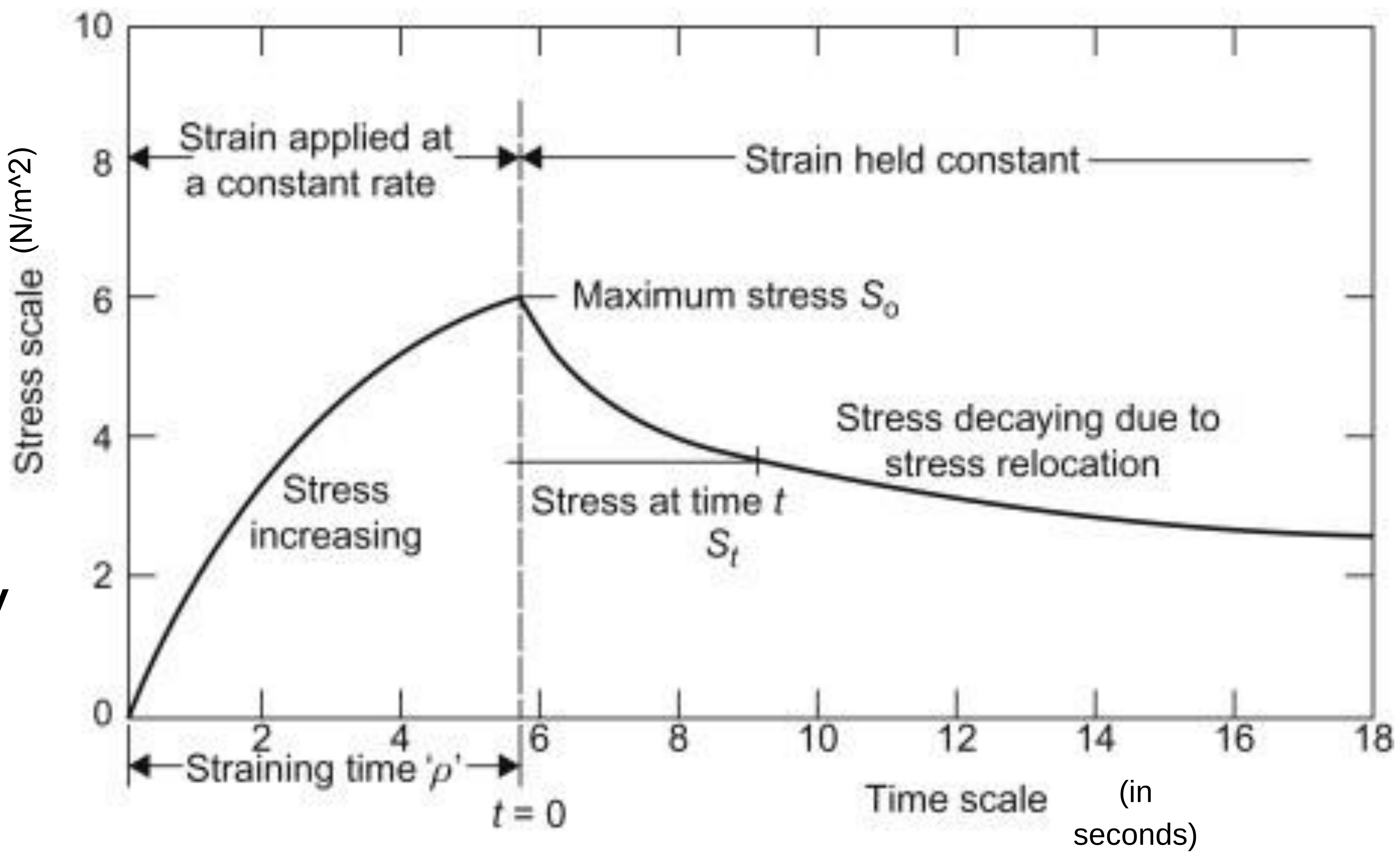




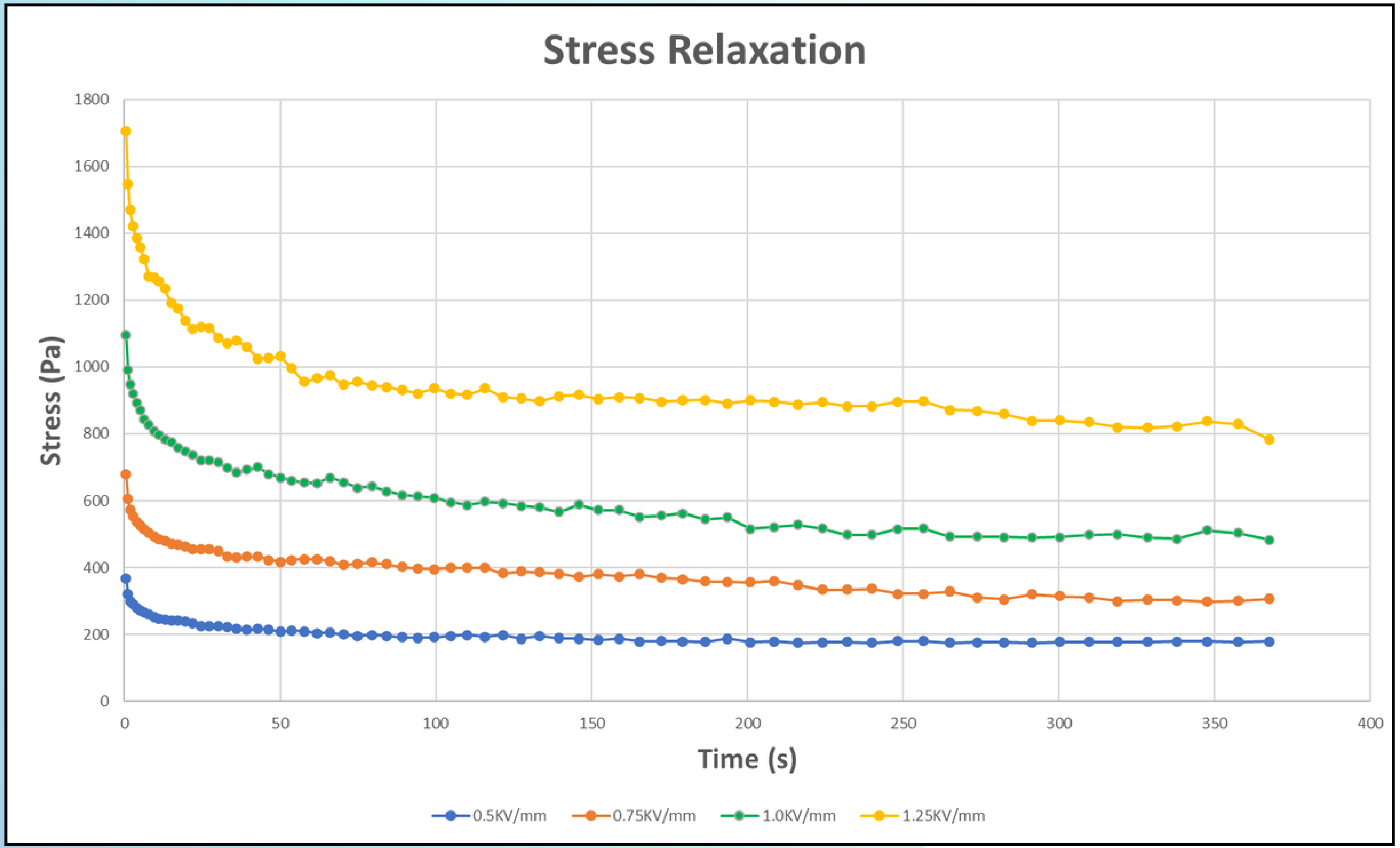
Since we were not provided with the input parameter sigma(o), we were not able to find a good fit for the data in the recovery part. However, we were lucky enough to obtain an R-squared of 0.89 during the creep experiment.

STRESS RELAXATION EXPERIMENTS AT DIFFERENT E

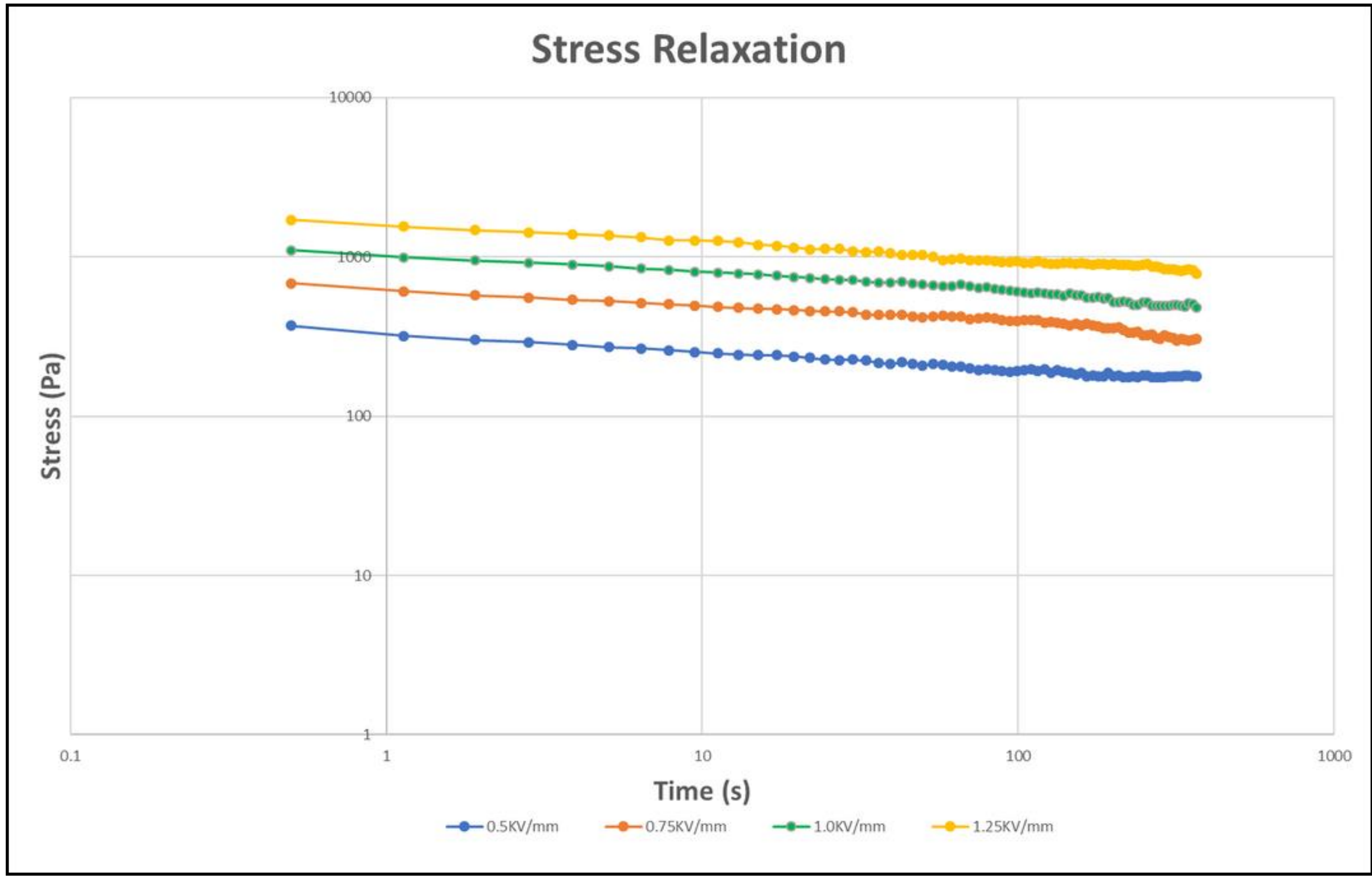
- Stress relaxation is the observed decrease in stress in response to a step strain generated in the structure.
- Stress relaxation describes how polymers relieve stress under constant strain. Because they are viscoelastic, polymers behave in a nonlinear, non-Hookean fashion
- Experimentally, stress relaxation is determined by step strain experiments, i.e. by applying a sudden one-time strain and measuring the build-up and subsequent relaxation of stress in the material



RESULTS

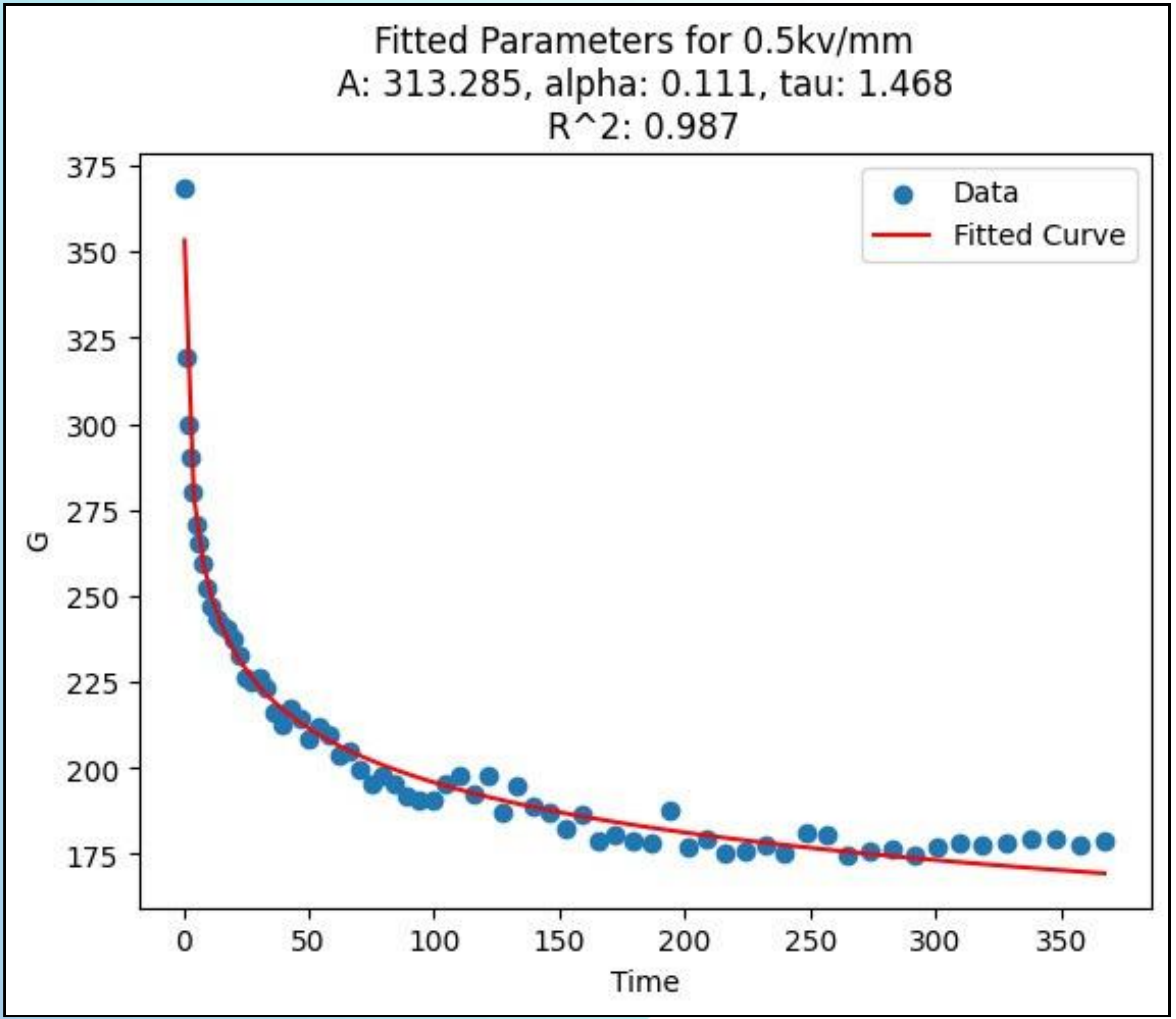


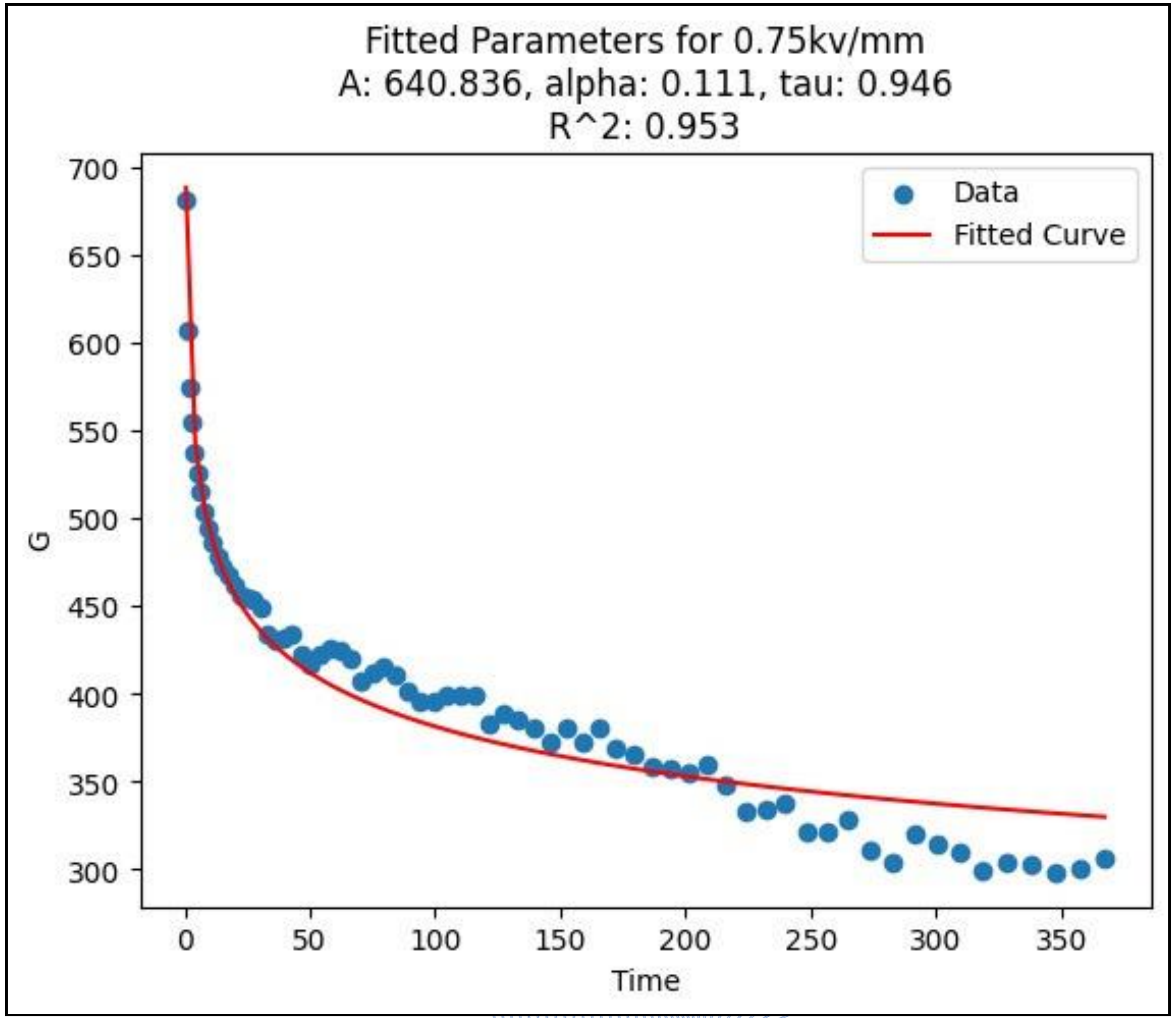
Linear-Linear



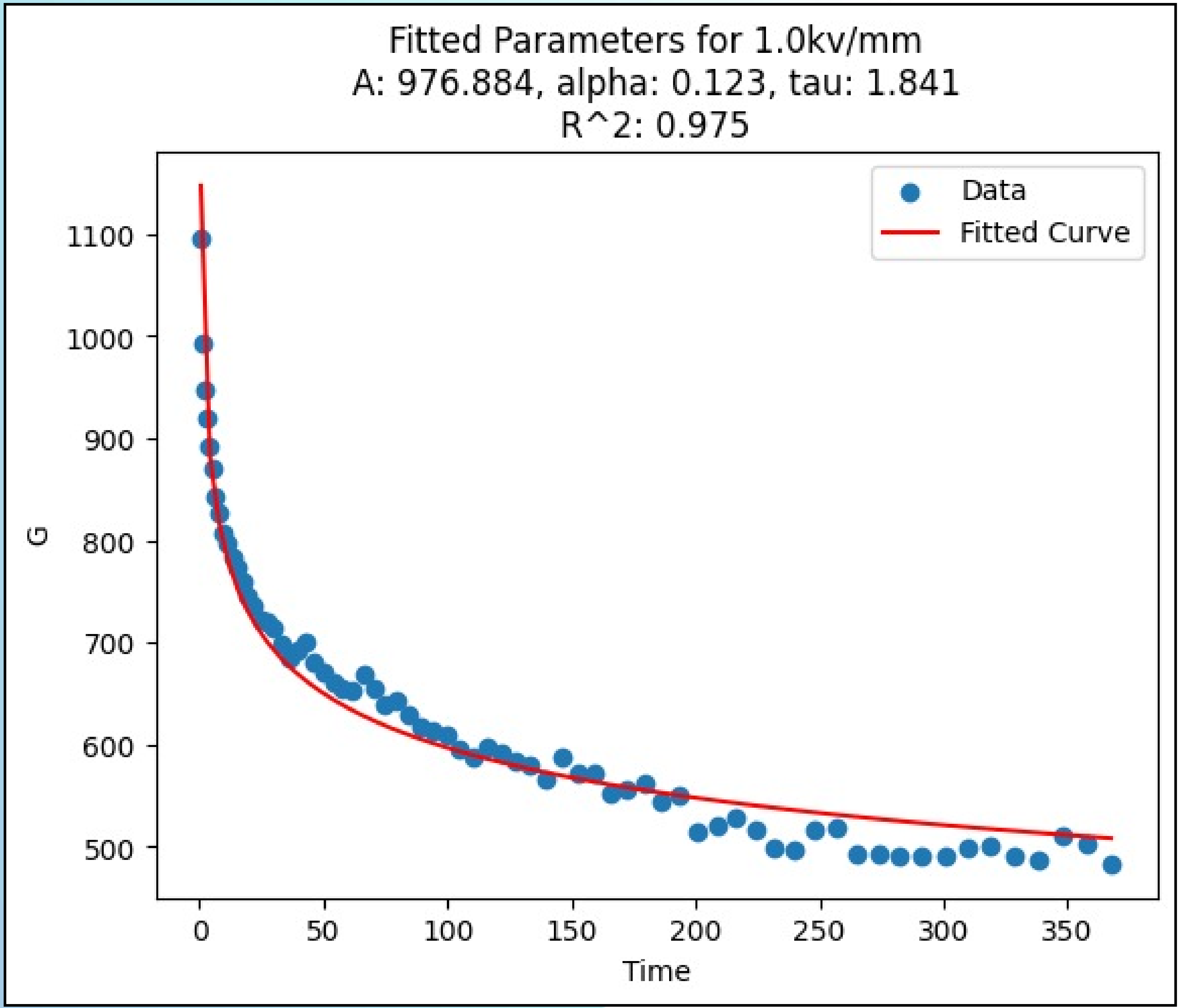
Log-Log

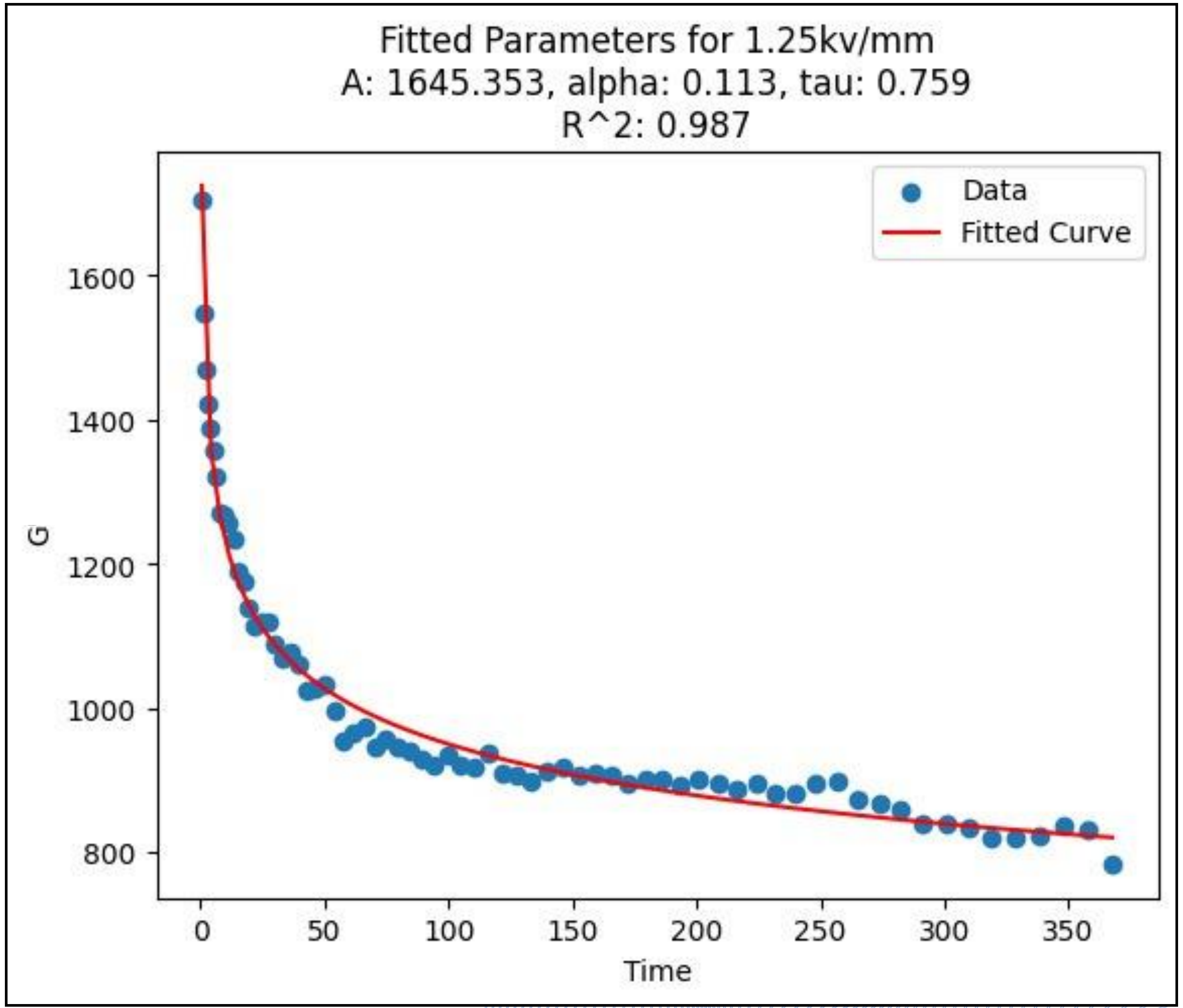
CURVE-FITTING(Power Law)
G=A.(t/τ)^(-α)





CURVE-FITTING(Power Law)
$G=A.(t/\tau)^{\wedge}(-\alpha)$





CONCLUSION

Electric Field (in kV/mm)	Time to relax 50% of initial stress (in seconds)
0.5	148
0.75	184
1.0	220
1.25	284

- When a larger voltage is put across the ER fluid, it relaxes more slowly than when a smaller voltage is applied. As we can see for 0.5KV/mm it takes approx. 148 seconds to relax 50% of its initial stress whereas it takes approx. 284 seconds for 1.25KV/mm.

- This is due to the fact that when voltage is increased, more chains are formed in the ER fluid, behaving more solid-like, resulting in an increase in relaxation time. As a result, an increase in voltage will result in an increase in the relaxation time of our ER fluid.

THANK YOU!

DO YOU HAVE ANY QUESTIONS?