PROCESSING THE RAW DATA FOR OSCILLATORY RHEOLOGY

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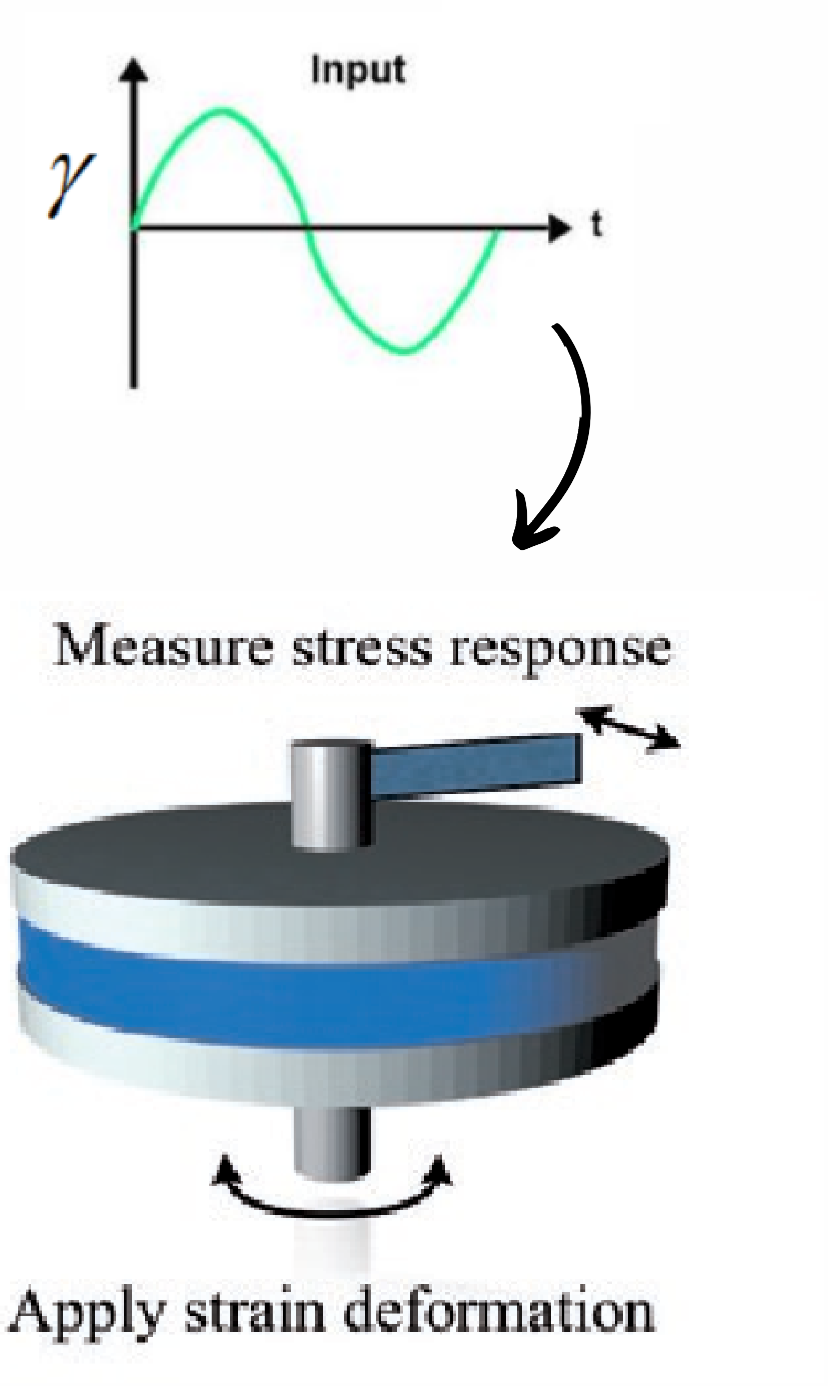
CONTENT

INTRODUCTION

Title: Processing the raw data for Oscillatory Rheology



- Oscillatory rheology investigates the dynamic mechanical properties of materials
- It involves subjecting materials to cyclic deformation, typically through oscillatory shear or strain
- Essential for understanding the material behaviour and how materials respond to dynamic forces
- Widely used in industries like pharmaceuticals, food, polymers, and petrochemicals

OBJECTIVES

- Fit a sinusoidal curve to the discrete values of output stress obtained from input strain data
- Investigate how the storage modulus (G') and loss modulus (G'') vary with different strain amplitudes
- Investigate the impact of strain frequency on G' and G'' to determine how the material's rheological properties change with different oscillation rates
- Analyse the linear and non-linear regimes in the material's behaviour, providing insights into its response to deformation across different conditions

EXPERIMENTAL SETUP

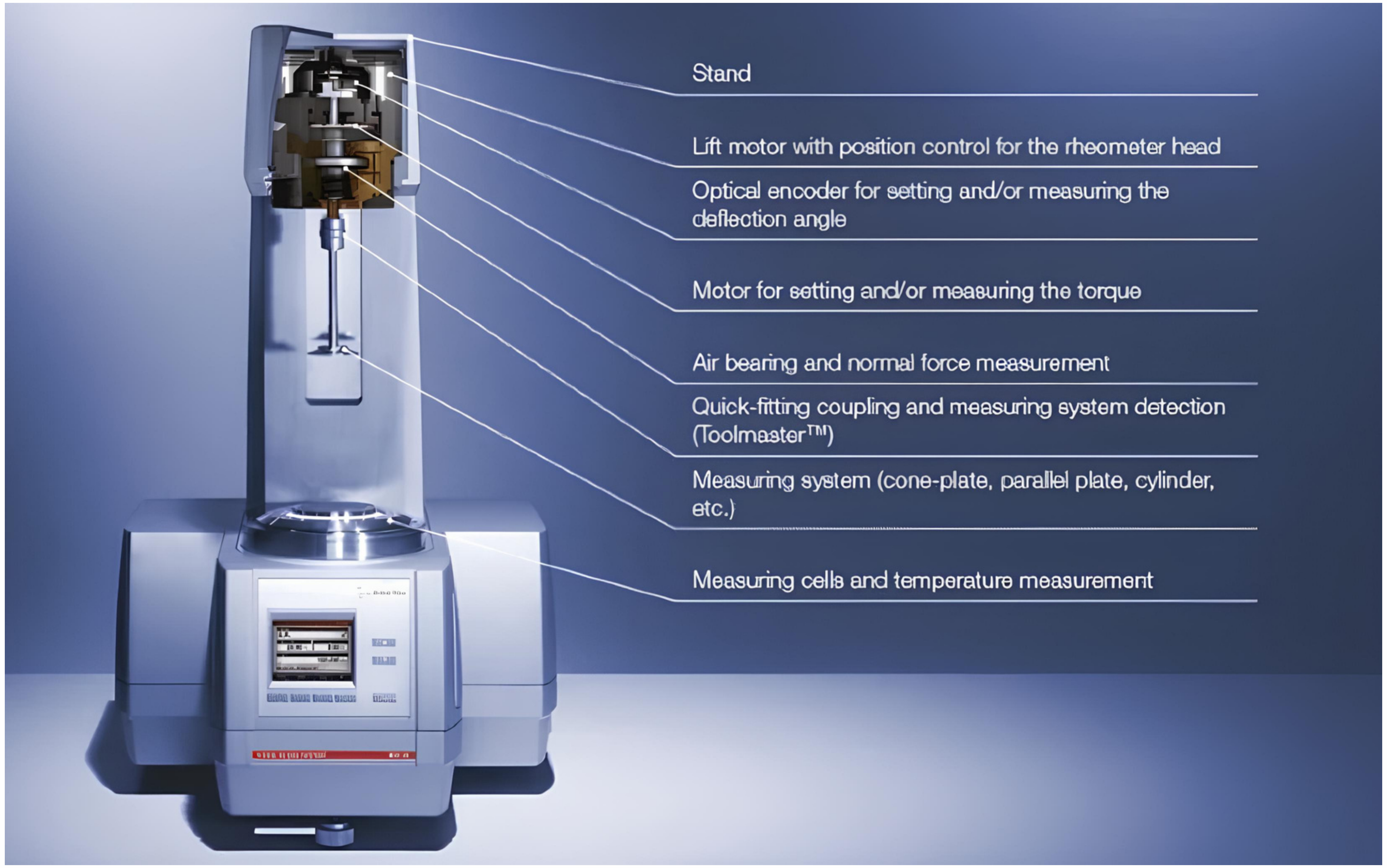


Fig. Rheometer

- **Material** : Corn starch mixed with silicone oil 40 wt%
- **Set gap** = 1mm

EXPERIMENTAL SETUP

DATASET DESCRIPTION

Input Shear Strain Function: $\Upsilon = \Upsilon_o sin(\varpi t)$

Strain Amplitude Variation

- Number of Samples: 5
- Frequency = 0.1 Hz (constant)

Amplitude	Number of data points	Total Time
0.0001	20	10 s
0.0005	20	10 s
0.005	20	10 s
0.02	20	10 s
0.05	20	10 s

DATASET DESCRIPTION

Input Shear Strain Function: $\Upsilon = \Upsilon_o sin(\varpi t)$

Frequency Variation

- Number of Samples: 4
- Amplitude : 0.005 (constant)

Frequency	Number of data points	Total Time
0.01 Hz	100	100 s
0.05 Hz	40	20 s
0.5 Hz	20	2 s
1 Hz	10	1 s

THEORY

1. Oscillatory Rheology

- Oscillatory rheology is a method for measuring the time-dependent behavior of a sample by **varying the frequency** of the applied stress or strain.

- In an oscillatory test, a specimen is subjected to an **oscillatory strain**. The response is used to obtain the elastic and viscous or damping characteristics.

- Oscillatory rheology is important when testing materials that may undergo macro- or micro-structural rearrangement with time.

2. Elastic/Storage Modulas and Loss Modulas

- By applying a sinusoidal strain profile we will get a sinusoidal stress output.
- We will fit the curve with the help of software and calculate amplitude and phase differences.
- Once both those values are known, we can calculate G’ and G”

$$G' = \sigma_o \cos(\phi) / \varphi_o$$

Elastic/Storage Modulus
Measures the energy stored in a material. It's related to the material's ability to store energy elastically.

$$G'' = \sigma_o \sin(\phi) / \varphi_o$$

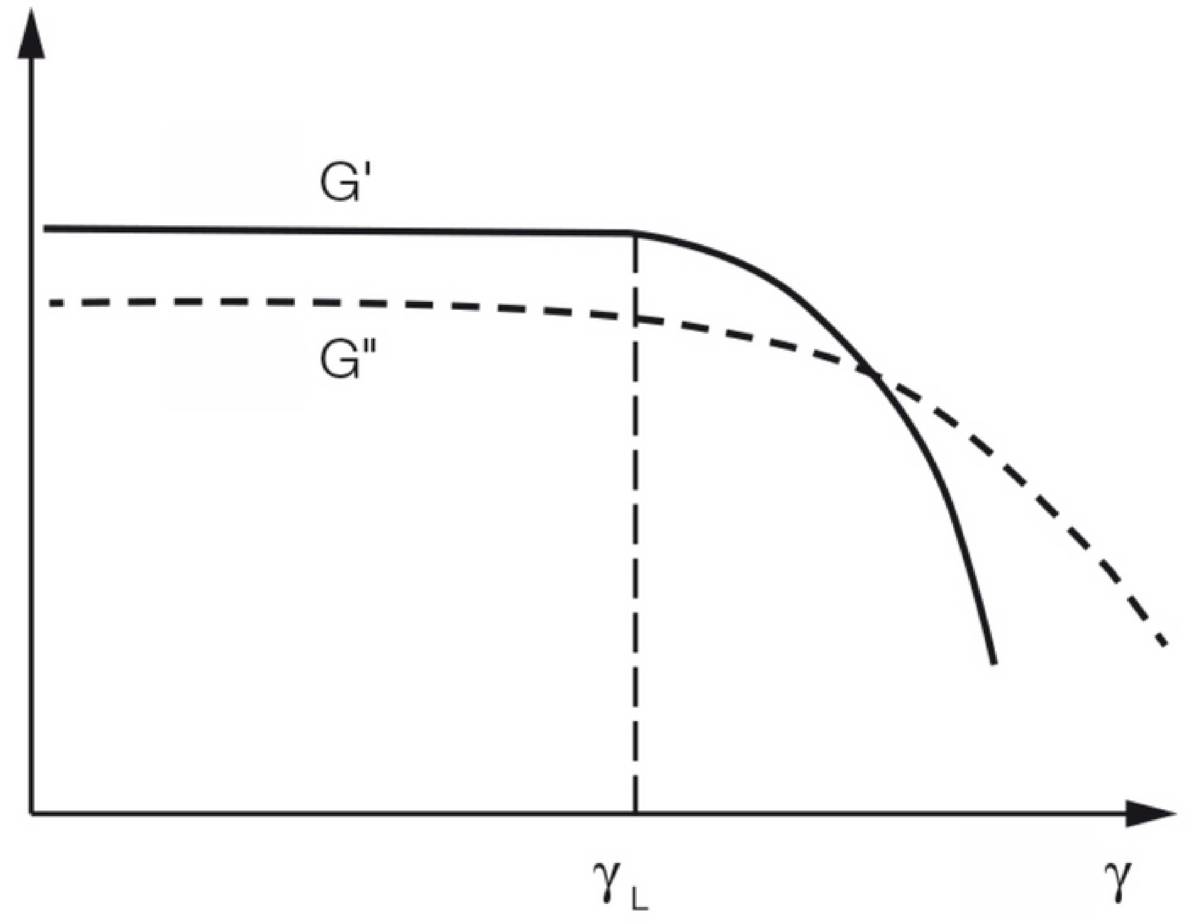
Loss Modulus
Measures the energy dissipated as heat. It's related to the material's ability to dissipate stress through heat.

3. Strain Amplitude Sweep Test

- A strain amplitude sweep test is a rheological test that uses increasing oscillatory strain at a **constant frequency**.

- In a strain amplitude sweep test, the frequency is set at a constant value while the strain is swept from 0.1% to 100%. The amplitude is the maximum of the oscillatory motion. The storage modulus G' and the loss modulus G'' are plotted against the deformation.

- The graph profile till gamma_L is under the **linear regime** because the shape the curve is a straight line.

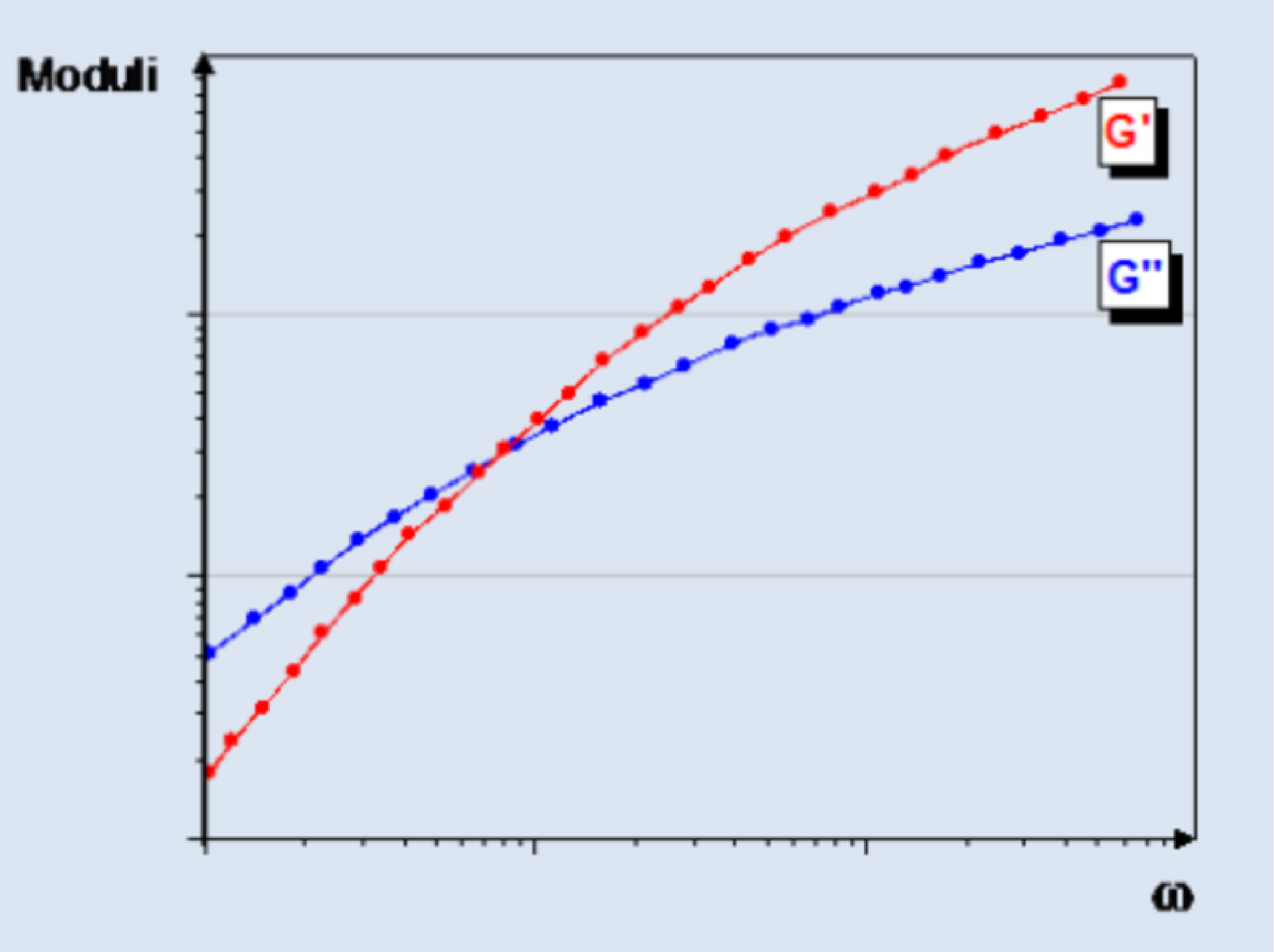


4. Frequency Sweep Test

- The objective of a frequency sweep test in rheology is to characterize the viscoelastic properties of a material as a **function of frequency**.

- The frequency of the oscillatory motion is varied over a specific range, typically from very low frequencies (e.g., 0.1 Hz) up to high frequencies (e.g., 100 Hz or more). The experiment is usually performed with a **constant amplitude**.

- With increasing frequency, G' increases more rapidly than G". The intersection point of G' and G" is known as the **cross-over frequency**.



FITTING SINUSOIDAL CURVE

```python
import numpy, scipy.optimize

def fit_sin(tt, yy):

    tt = numpy.array(tt)
    yy = numpy.array(yy)
    ff = numpy.fft.fftfreq(len(tt), (tt[1]-tt[0]))
    Fyy = abs(numpy.fft.fft(yy))
    guess_freq = abs(ff[numpy.argmax(Fyy[1:])+1])
    guess_amp = numpy.std(yy) * 2.**0.5
    guess_offset = numpy.mean(yy)
    guess = numpy.array([guess_amp, 2.*numpy.pi*guess_freq, 0., guess_offset])
    def sinfunc(t, A, w, p, c):  return A * numpy.sin(w*t + p) + c
    popt, pcov = scipy.optimize.curve_fit(sinfunc, tt, yy, p0=guess)
    A, w, p, c = popt
    f = w/(2.*numpy.pi)
    fitfunc = lambda t: A * numpy.sin(w*t + p) + c
    return {"amp": A, "omega": w, "phase": p, "offset": c, "freq": f, "period": 1./f}
```

$$x[k] = \sum_{n=0}^{N-1} x[n] e^{\frac{-j2\pi kn}{N}}$$

INITIAL GUESSES

- Guess frequency is decided by Fast Fourier Transform.
- Guess Amplitude = sqrt(2*std_dev(stress datapoints))
- Guess offset = mean(stress datapoints)
- Guess phase difference=0

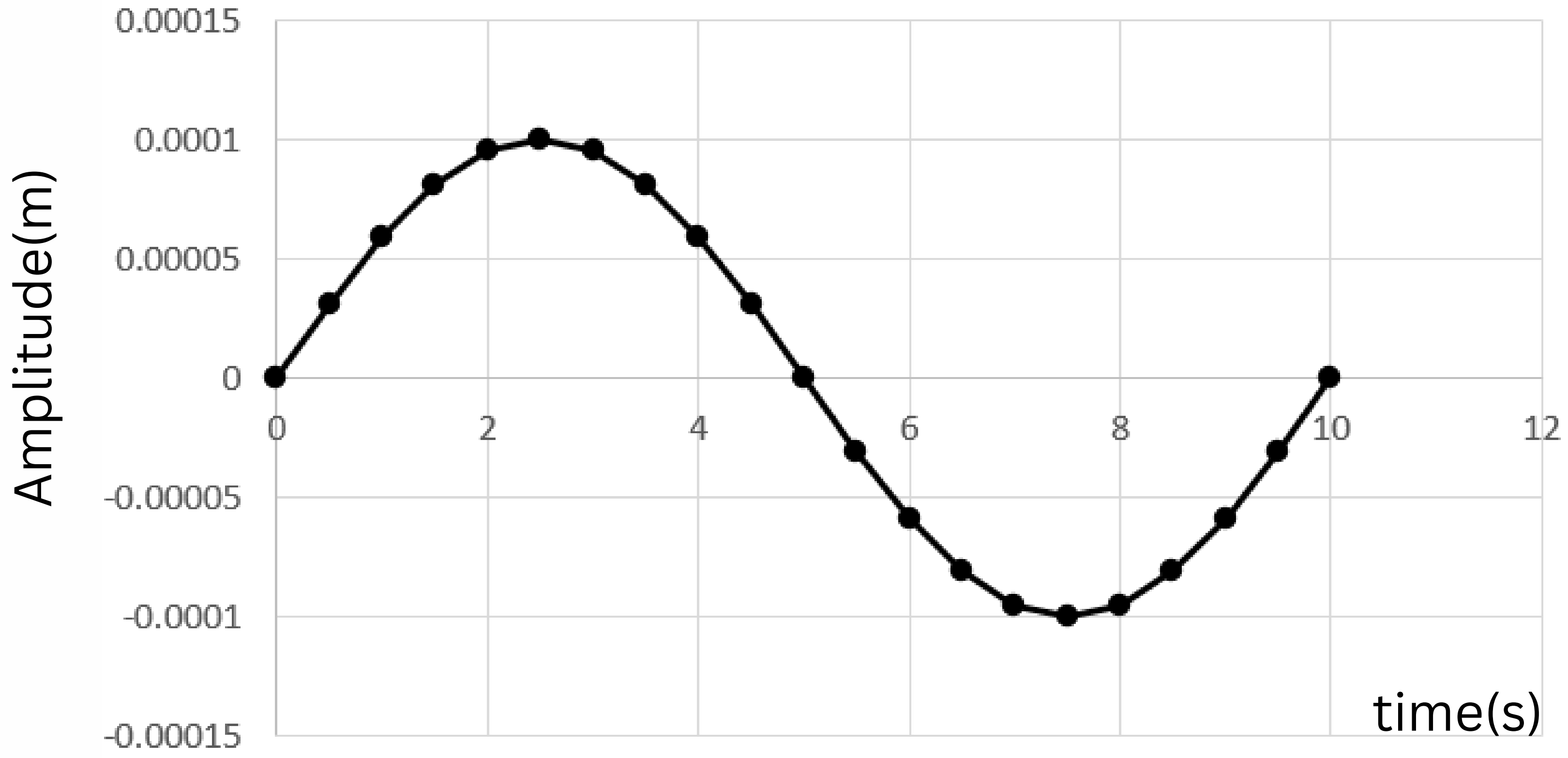
LEVENBERG-MARQUARDT ALGORITHM(PSEUDO CODE)

```
function LevenbergMarquardt(data, parameters, max_iterations, tolerance)
    initialize: lambda = initial_lambda
    for iteration in 1 to max_iterations
       compute: objective_function_value = EvaluateObjectiveFunction(data, parameters)
       compute: gradient = ComputeGradient(data, parameters)
       compute: hessian = ComputeHessian(data, parameters)
       update: delta_parameters = SolveLinearSystem(hessian + lambda * identity_matrix, -gradient)
       update: new_parameters = parameters + delta_parameters
       compute: new_objective_function_value = EvaluateObjectiveFunction(data, new_parameters)
       if new_objective_function_value < objective_function_value
          accept the parameter update: parameters = new_parameters
          update: lambda = lambda / decrease_factor
       else
          reject the parameter update
          update: lambda = lambda * increase_factor
     if convergence criteria met (e.g., norm of gradient < tolerance)
       break
     return parameters
end function
```

STRAIN AMPLITUDE SWEEP TEST

DATA 1

Shear Strain (Input)



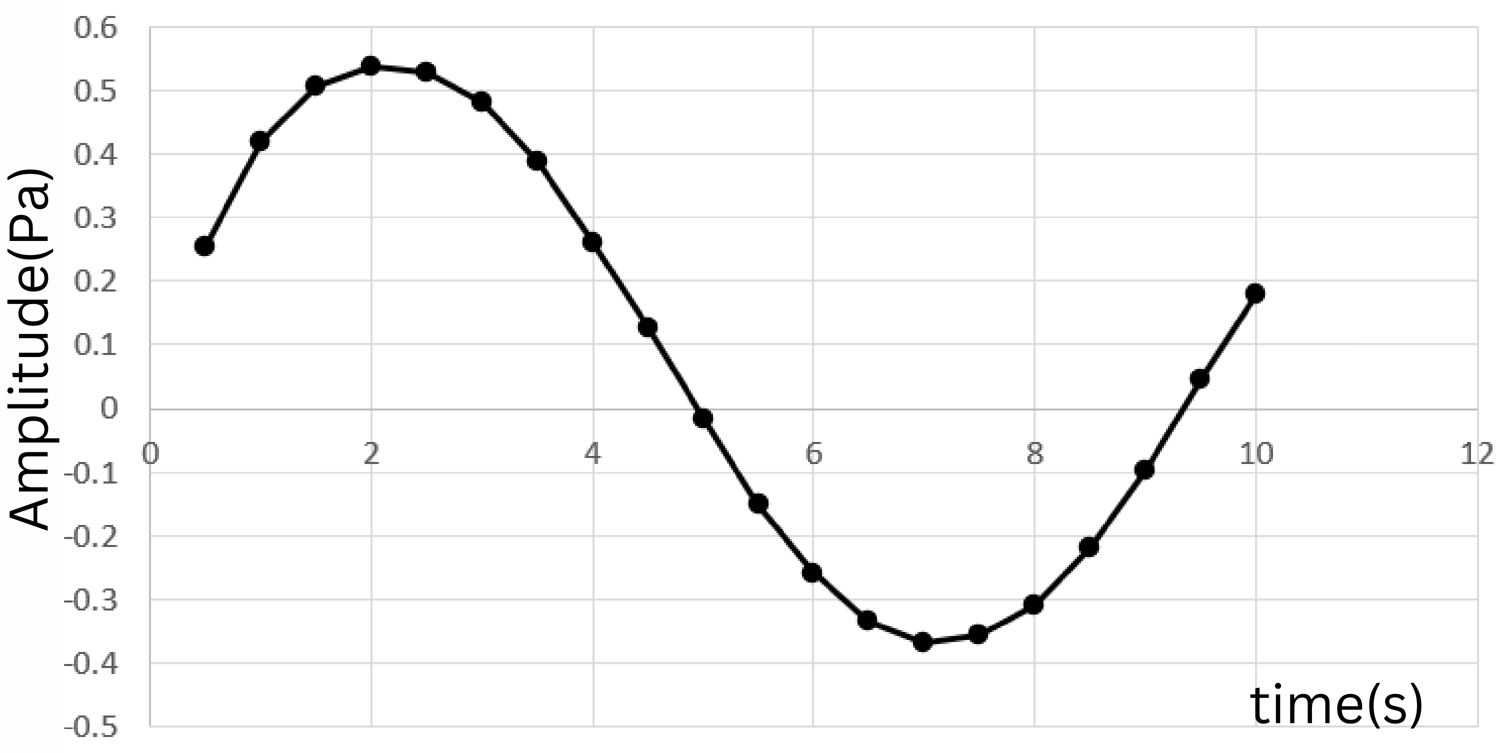
$$\Upsilon = \Upsilon_o sin(\varpi t)$$

Input sinusoidal curve:

Υ_o = 0.0001

f = 0.1 Hz

Stress (Output)



$$\sigma = \sigma_o sin(\varpi t + \phi)$$

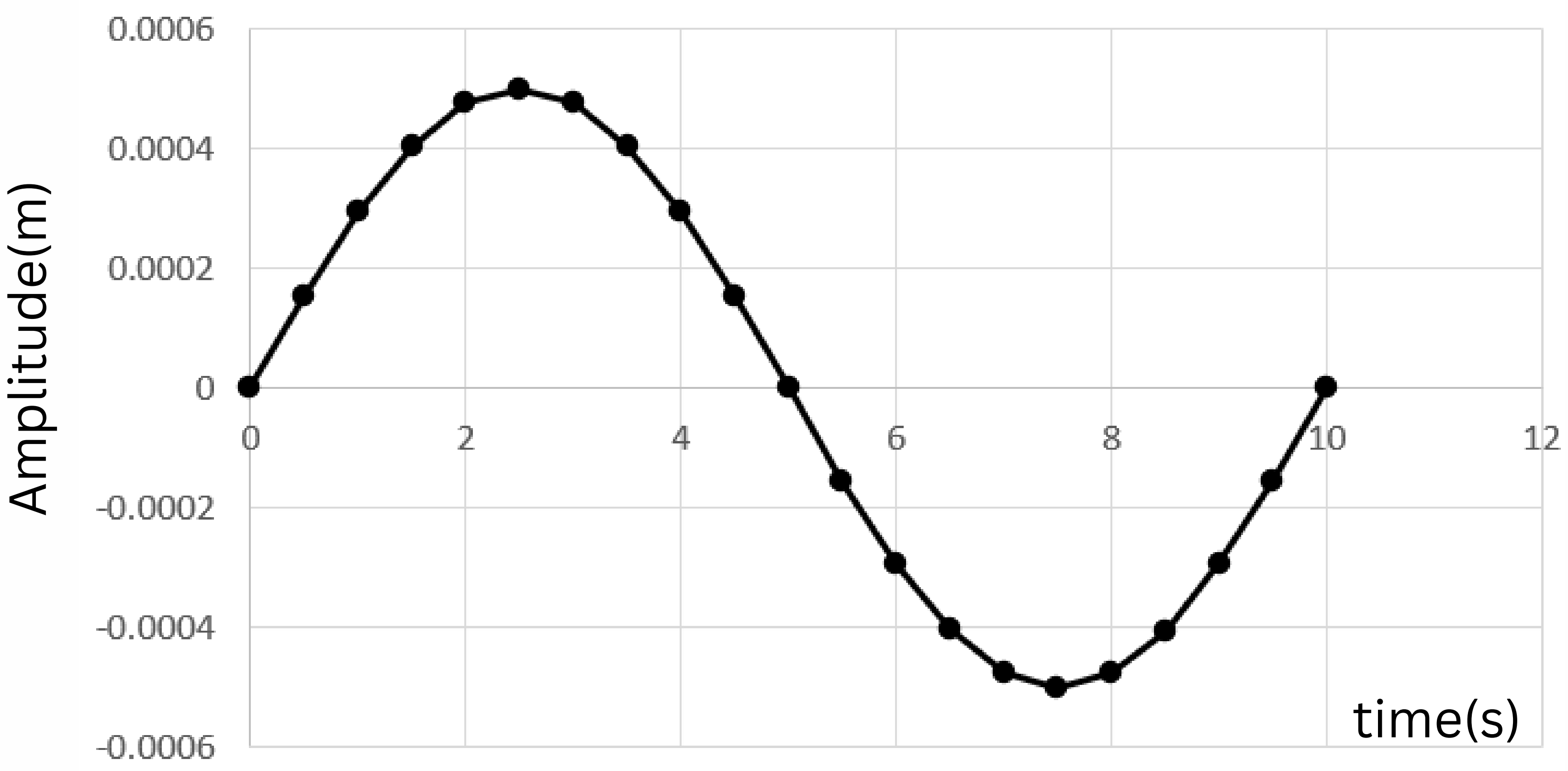
Best Fit sinusoidal curve:

σ_o = 0.4548 Pa

ϕ = 0.1580 rad

DATA 2

Shear Strain (Input)



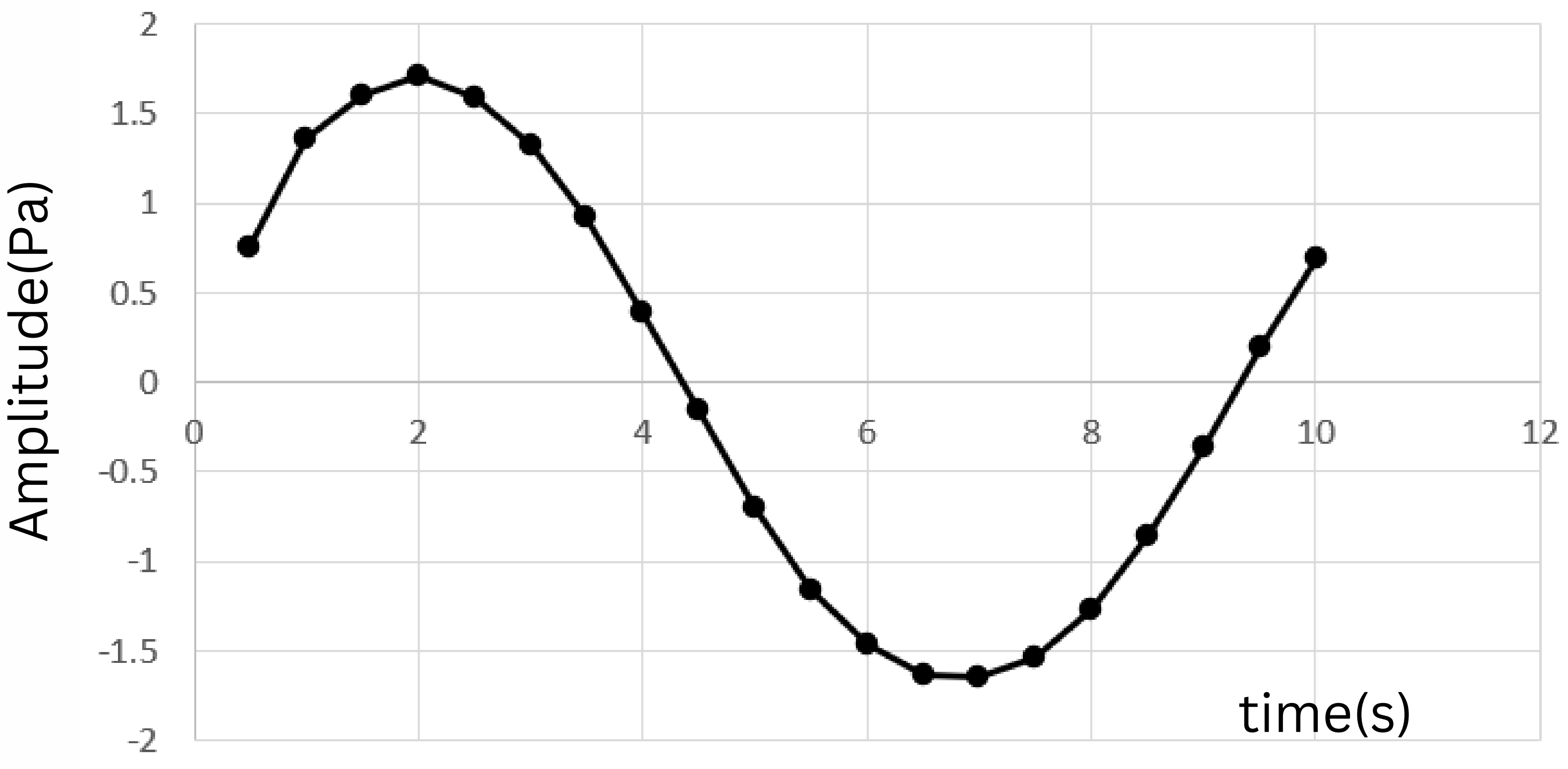
$$\Upsilon = \Upsilon_o sin(\varpi t)$$

Input sinusoidal curve:

Υ_o = 0.0005 m

f = 0.1 Hz

Stress (Output)



$$\sigma = \sigma_o sin(\varpi t + \phi)$$

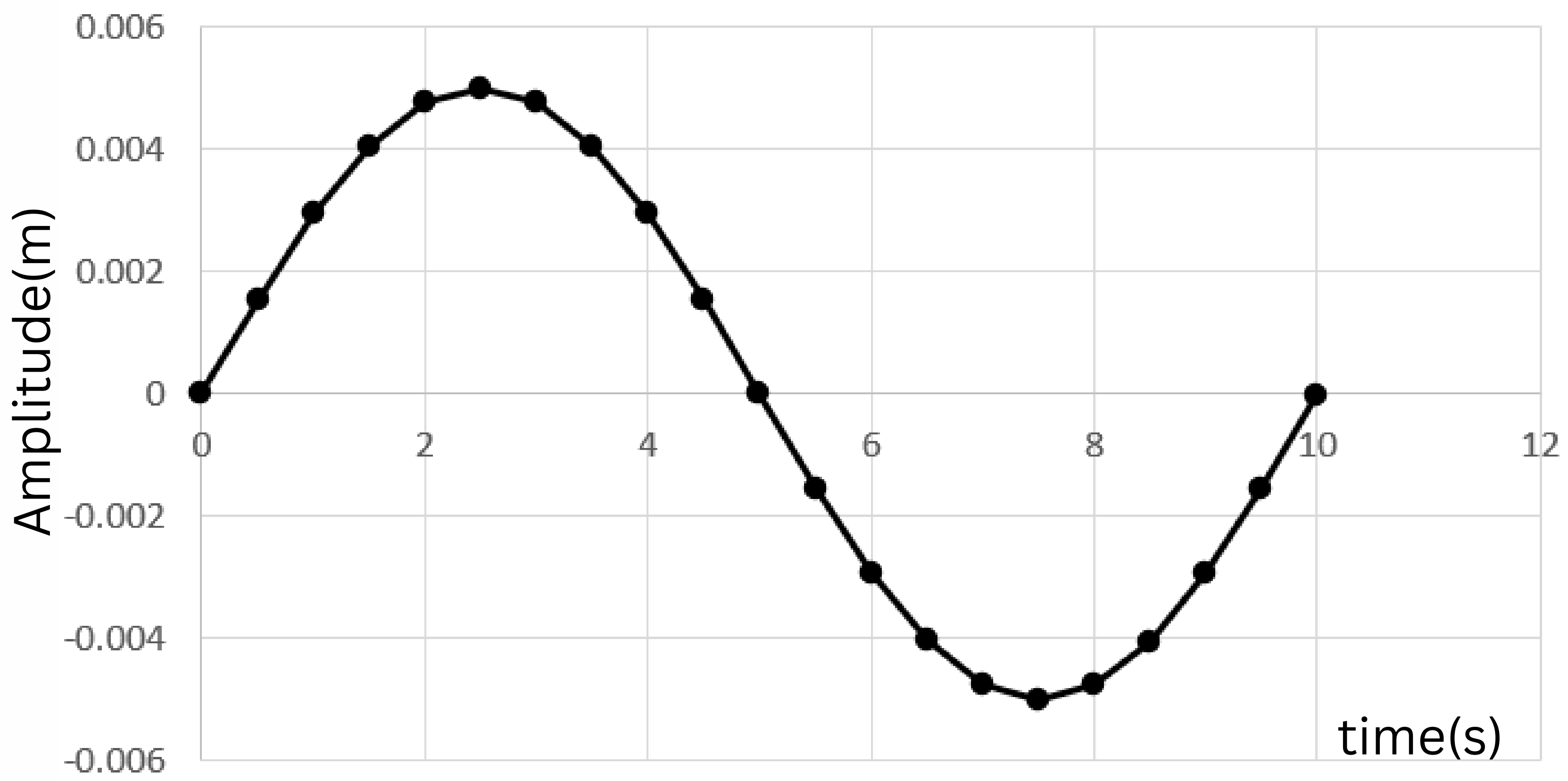
Best Fit sinusoidal curve:

σ_o = 1.682

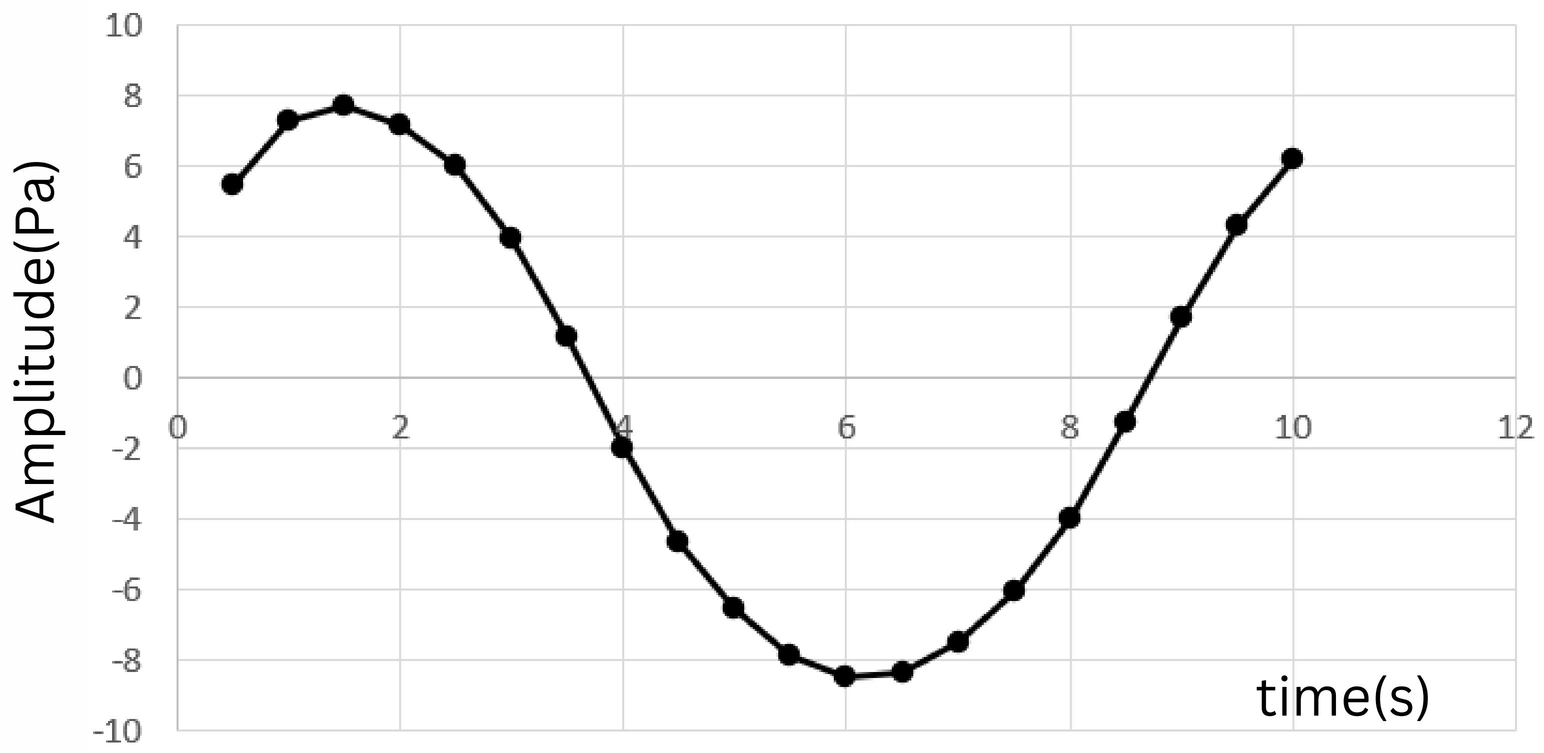
ϕ = 0.268

DATA 3

Shear Strain (Input)



Stress (Output)



$$\Upsilon = \Upsilon_o sin(\varpi t)$$

Input sinusoidal curve:

Υ_o = 0.005 m

f = 0.1 Hz

$$\sigma = \sigma_o sin(\varpi t + \phi)$$

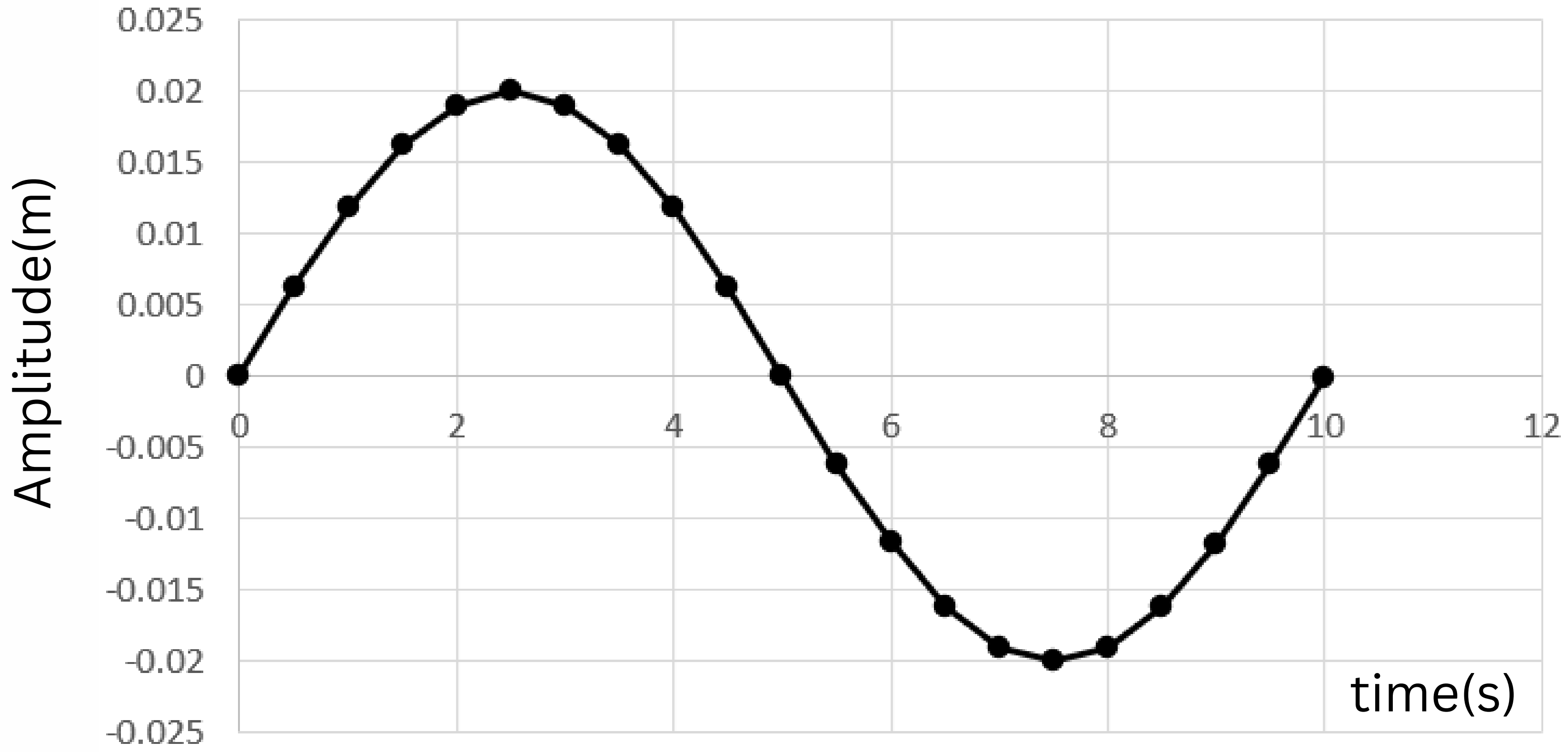
Best Fit sinusoidal curve:

σ_o = 8.227 Pa

ϕ = 0.581 rad

DATA 4

Shear Strain (Input)



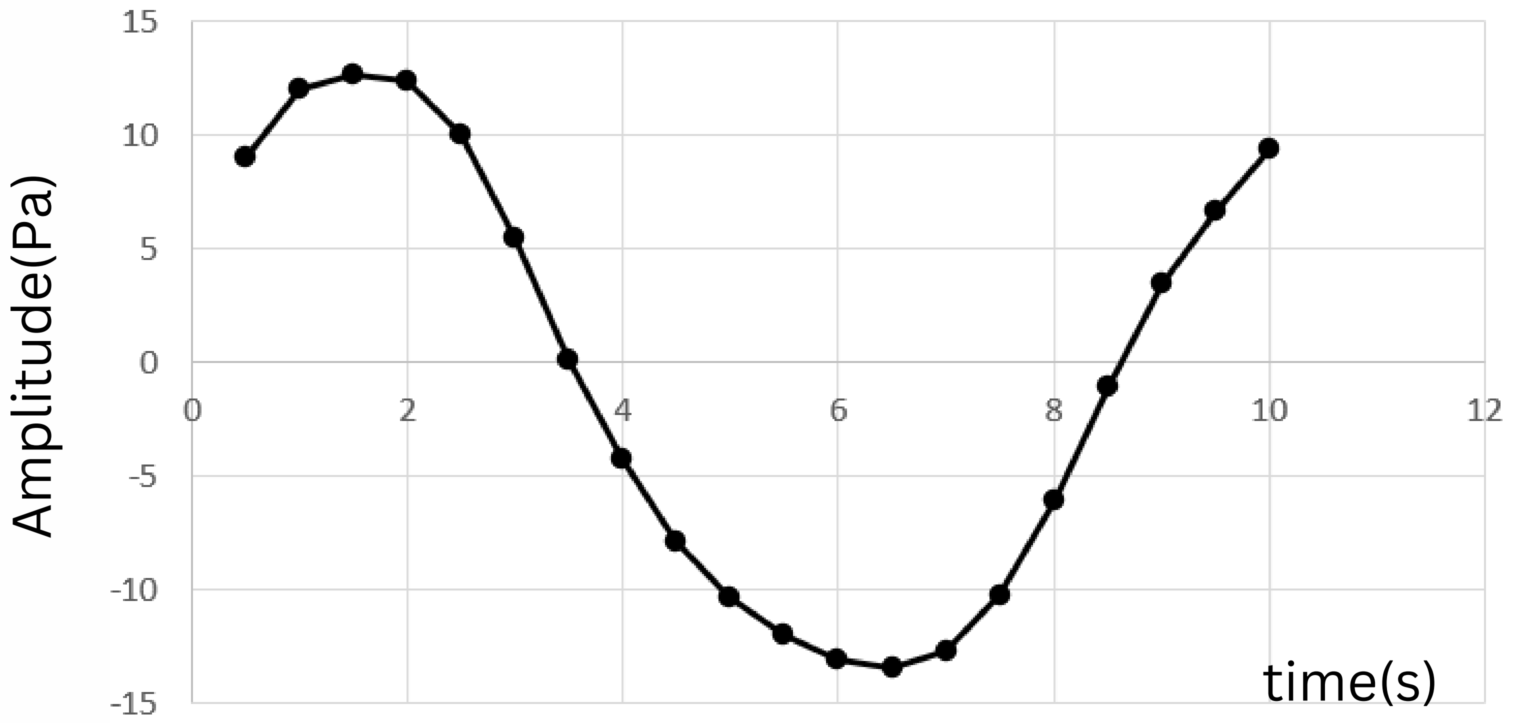
$$\Upsilon = \Upsilon_o sin(\varpi t)$$

Input sinusoidal curve:

Υ_o = 0.02 m

f = 0.1 Hz

Stress (Output)



$$\sigma = \sigma_o sin(\varpi t + \phi)$$

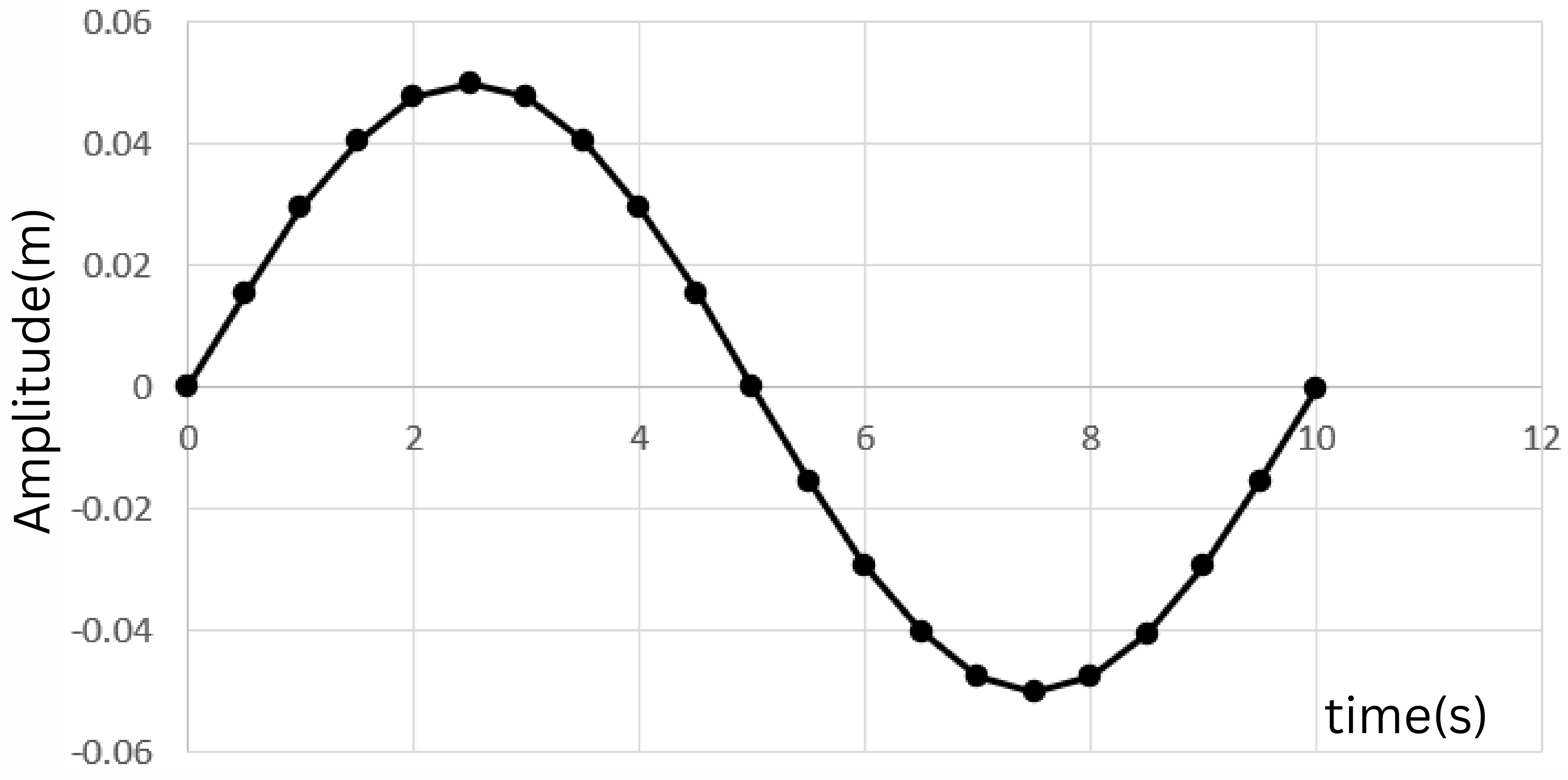
Best Fit sinusoidal curve:

σ_o = 13.25 Pa

ϕ = 0.654 rad

DATA 5

Shear Strain (Input)



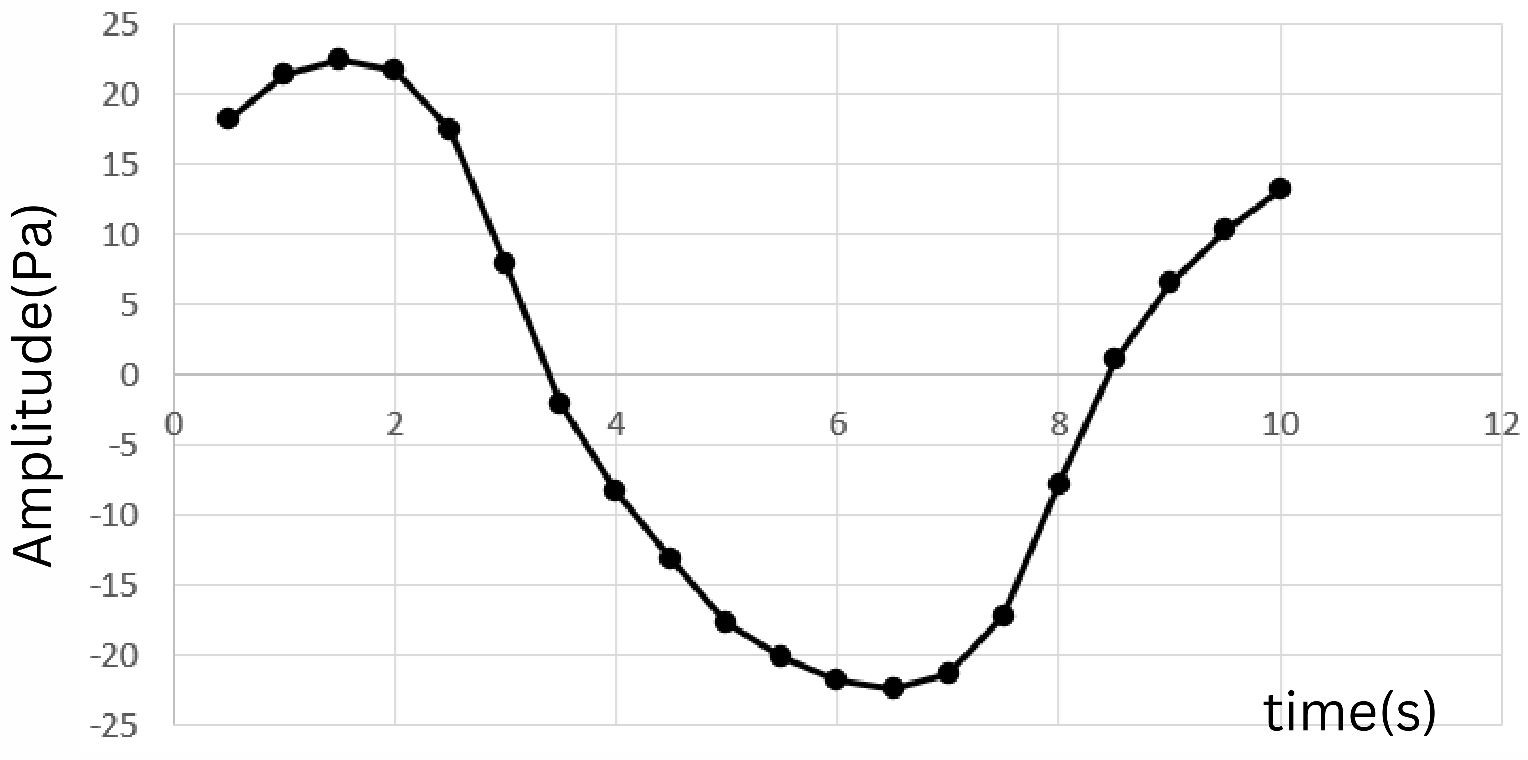
$$\Upsilon = \Upsilon_o sin(\varpi t)$$

Input sinusoidal curve:

Υ_o = 0.05 m

f = 0.1 Hz

Stress (Output)



$$\sigma = \sigma_o sin(\varpi t + \phi)$$

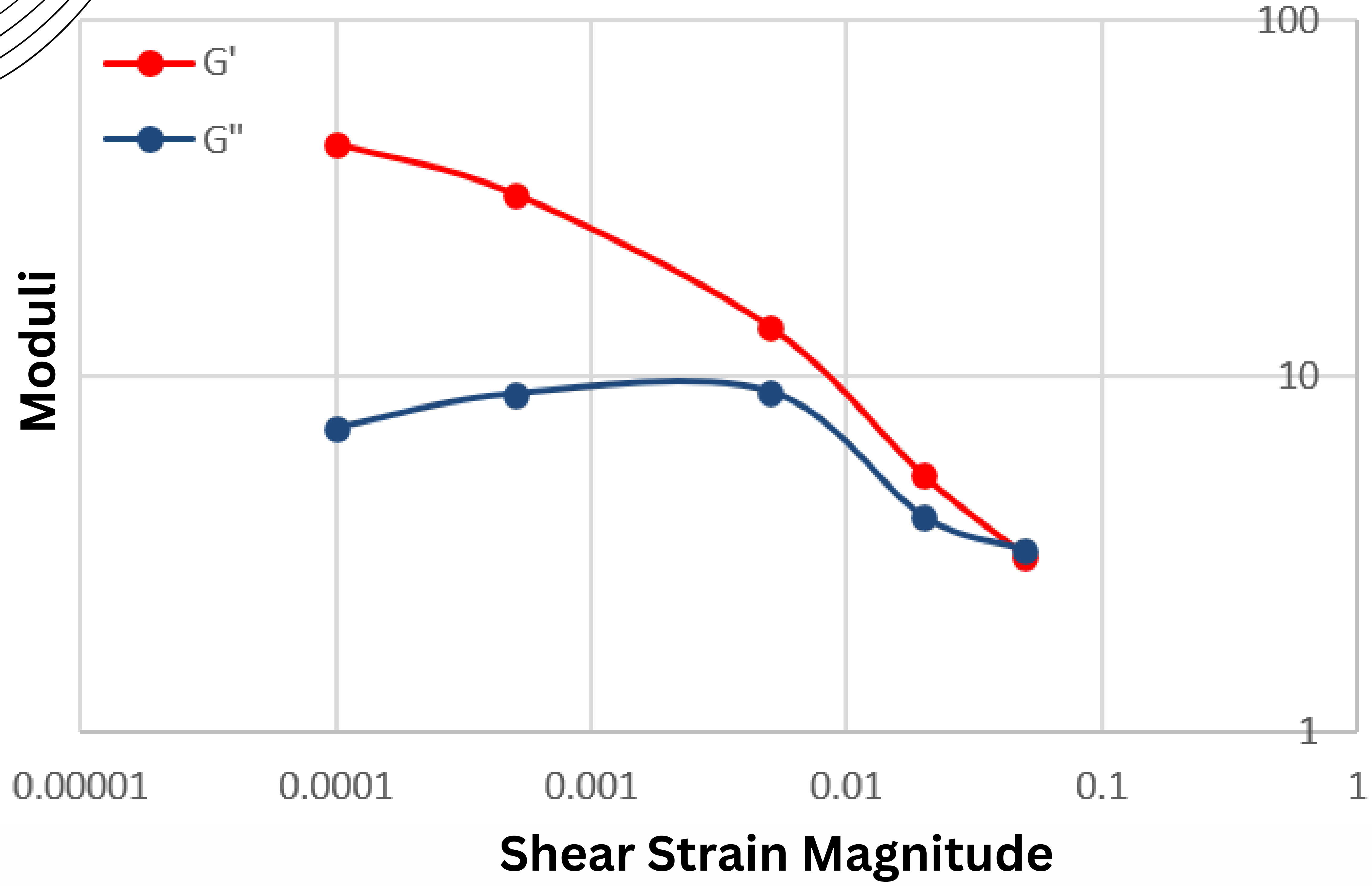
Best Fit sinusoidal curve:

σ_o = 22.56 Pa

ϕ = 0.81 rad

G’ AND G’’

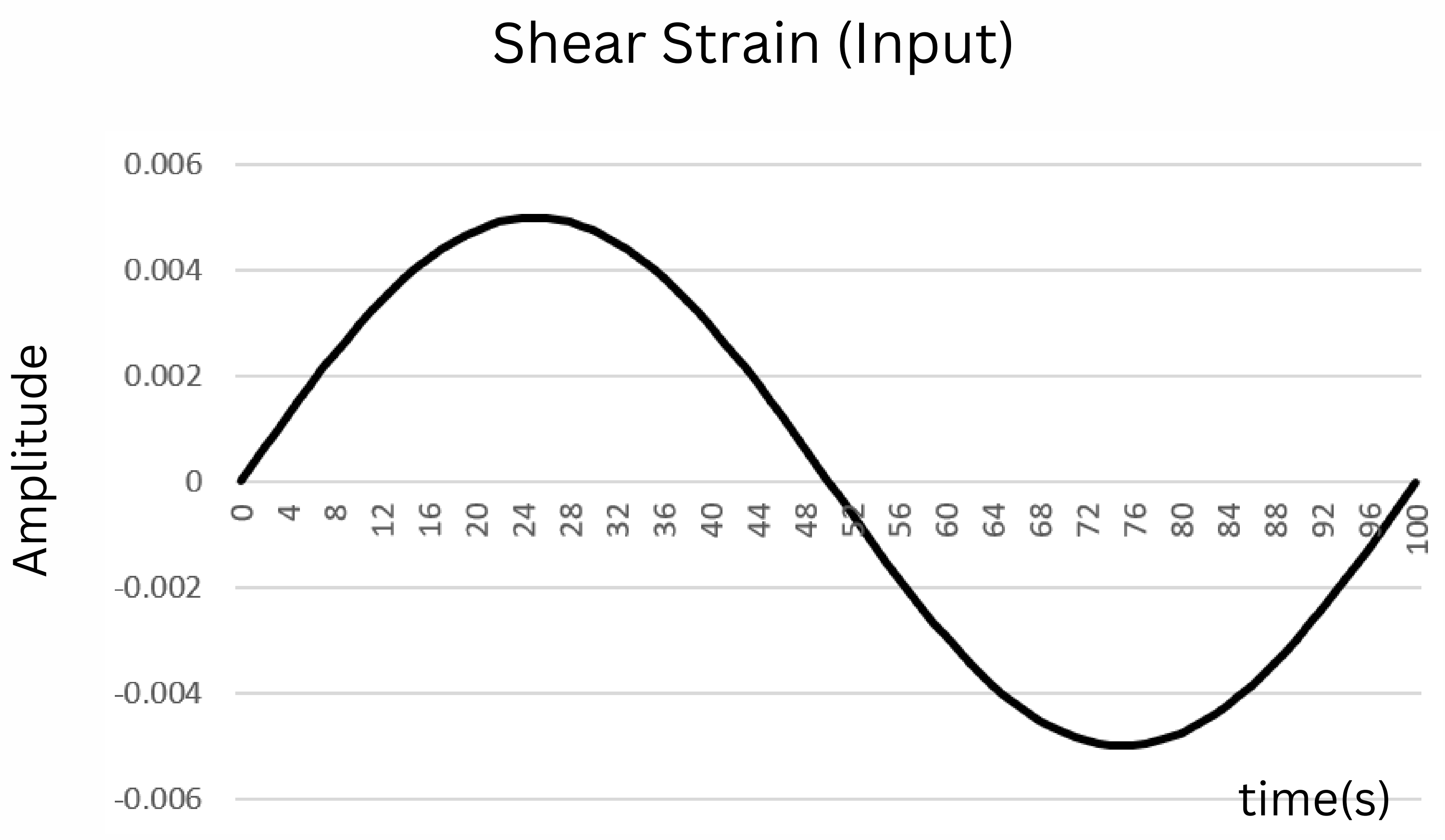
γ_o	f Hz	G’ Pa	G” Pa
0.0001	0.1 Hz	44.92	7.15
0.0005	0.1 Hz	32.45	8.92
0.005	0.1 Hz	13.748	9.04
0.02	0.1 Hz	5.260	4.033
0.05	0.1 Hz	3.127	3.25

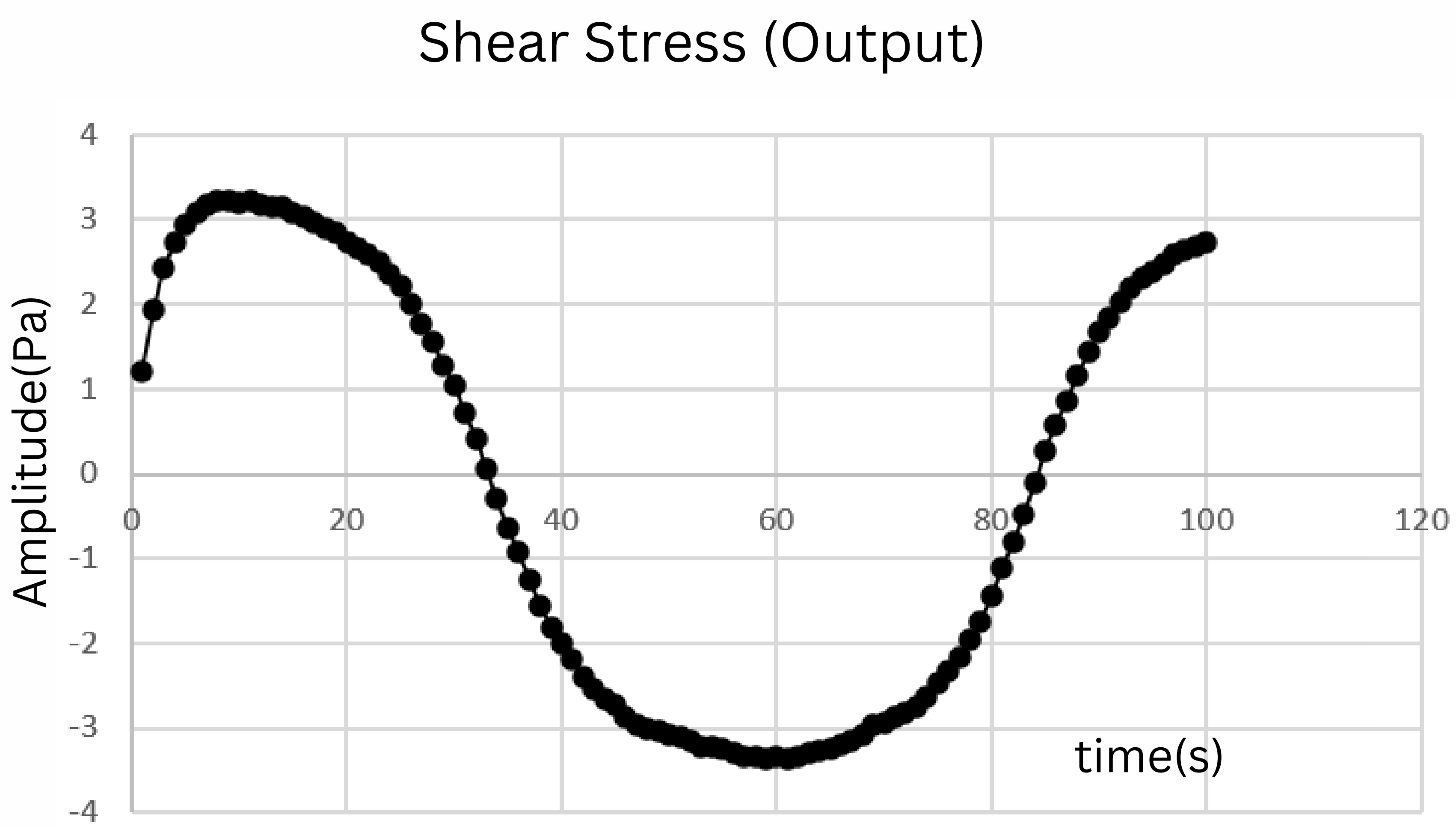


G'
G"
100
10
1
Moduli
0.00001
0.0001
0.001
0.01
0.1
1
Shear Strain Magnitude

FREQUENCY SWEEP TEST

DATA 1





$$\Upsilon = \Upsilon_o \sin(\varpi t)$$

Input sinusoidal curve:

$\Upsilon_o = 0.005$

$f = 0.01$ Hz

$$\sigma = \sigma_o \sin(\varpi t + \phi)$$

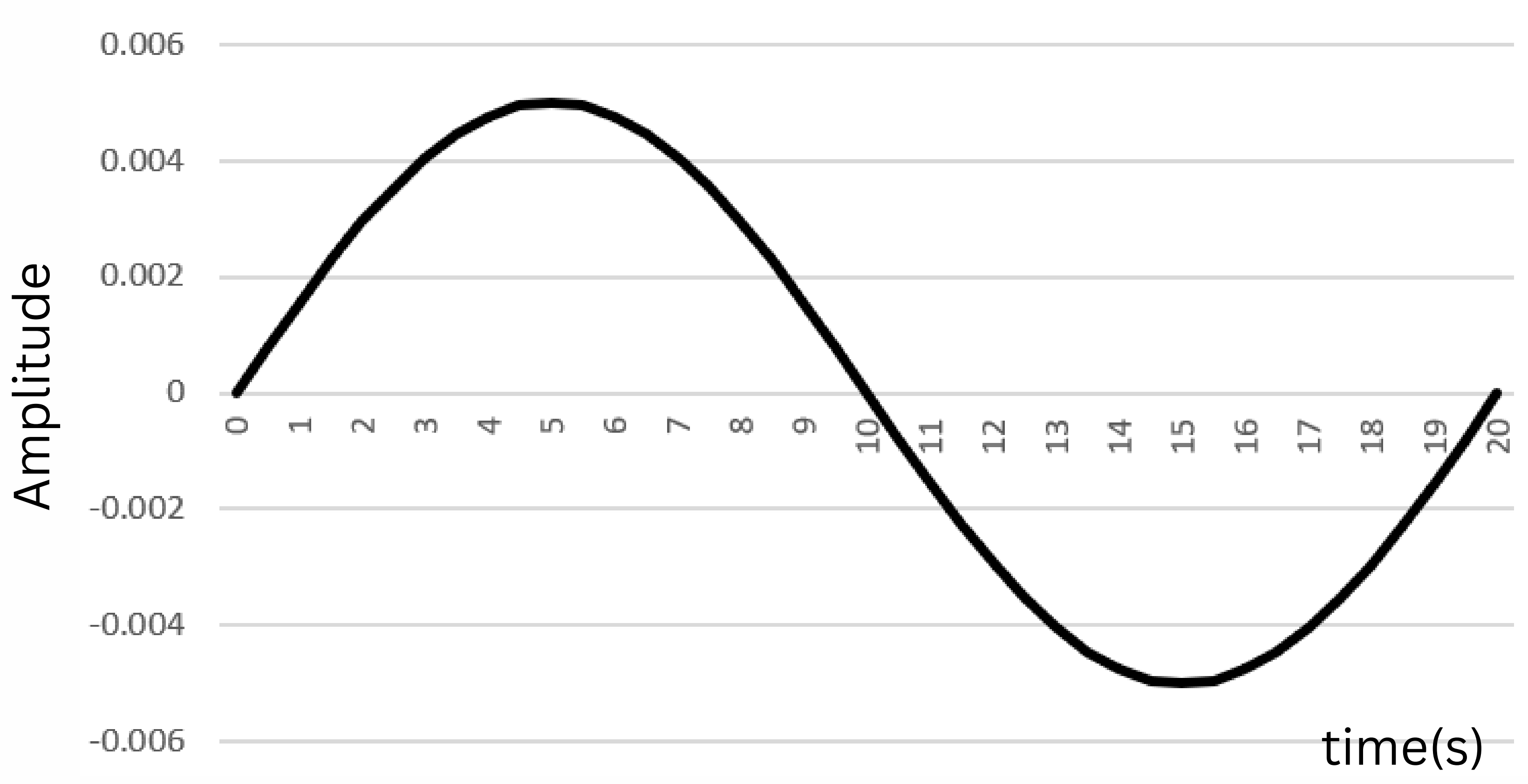
Best Fit sinusoidal curve:

$\sigma_o = 3.486$ Pa

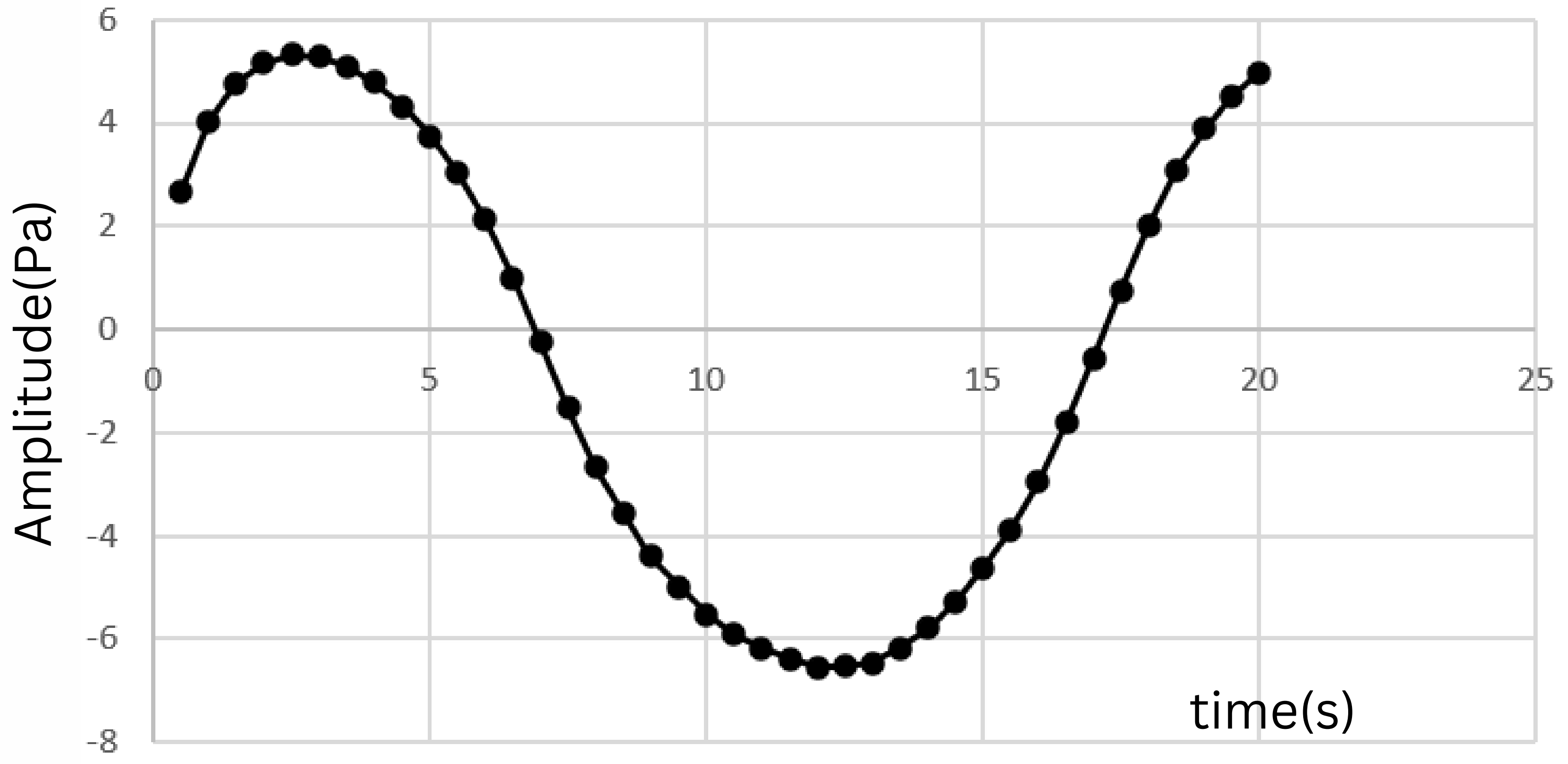
$\phi = 0.796$ rad

DATA 2

Shear Strain (Input)



Stress (Output)



$$\Upsilon = \Upsilon_o sin(\varpi t)$$

Input sinusoidal curve:

Υ_o = 0.005

f = 0.05 Hz

$$\sigma = \sigma_o sin(\varpi t + \phi)$$

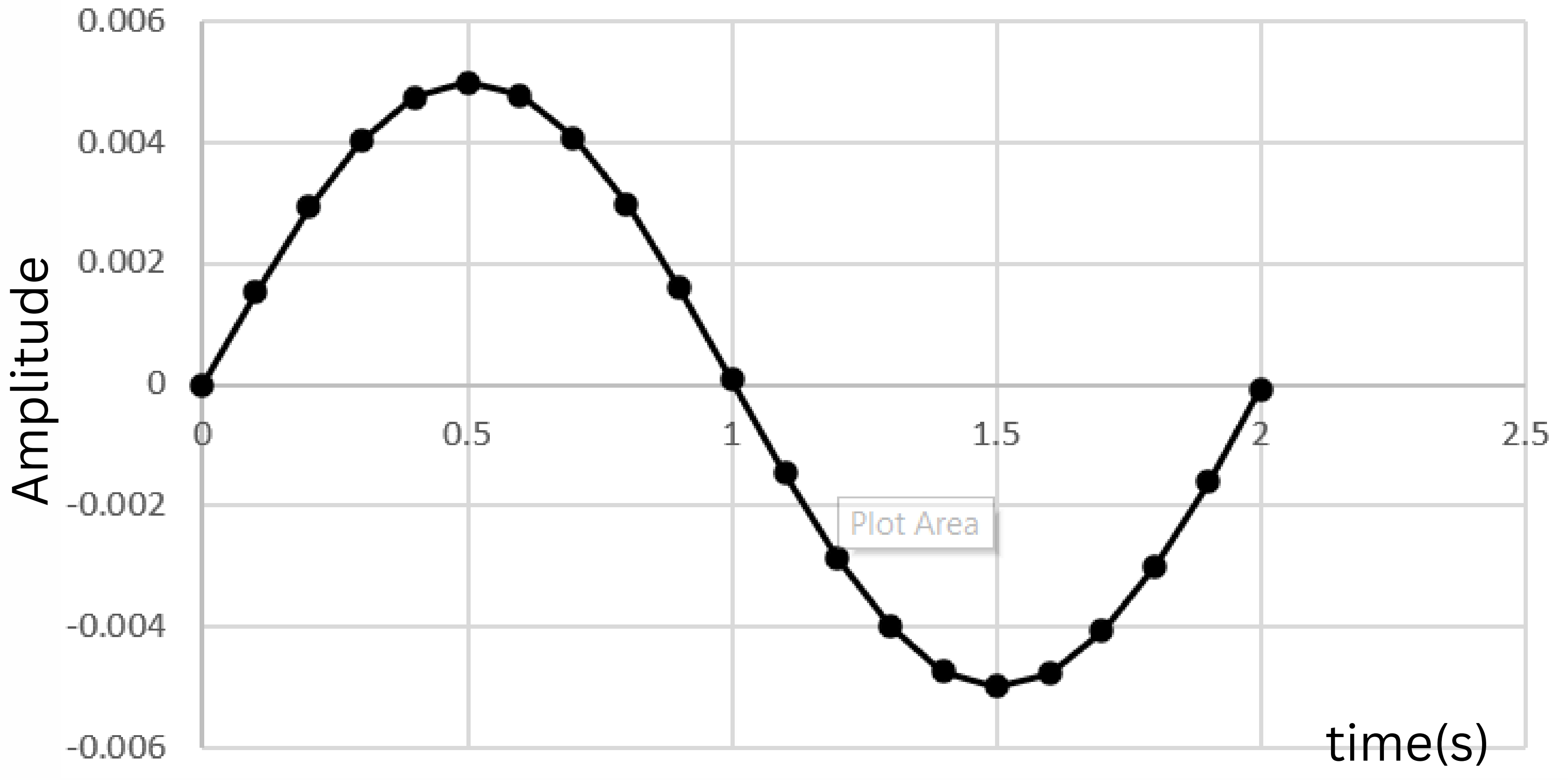
Best Fit sinusoidal curve:

σ_o = 6.151 Pa

ϕ = 0.616 rad

DATA 3

Shear Strain (Input)



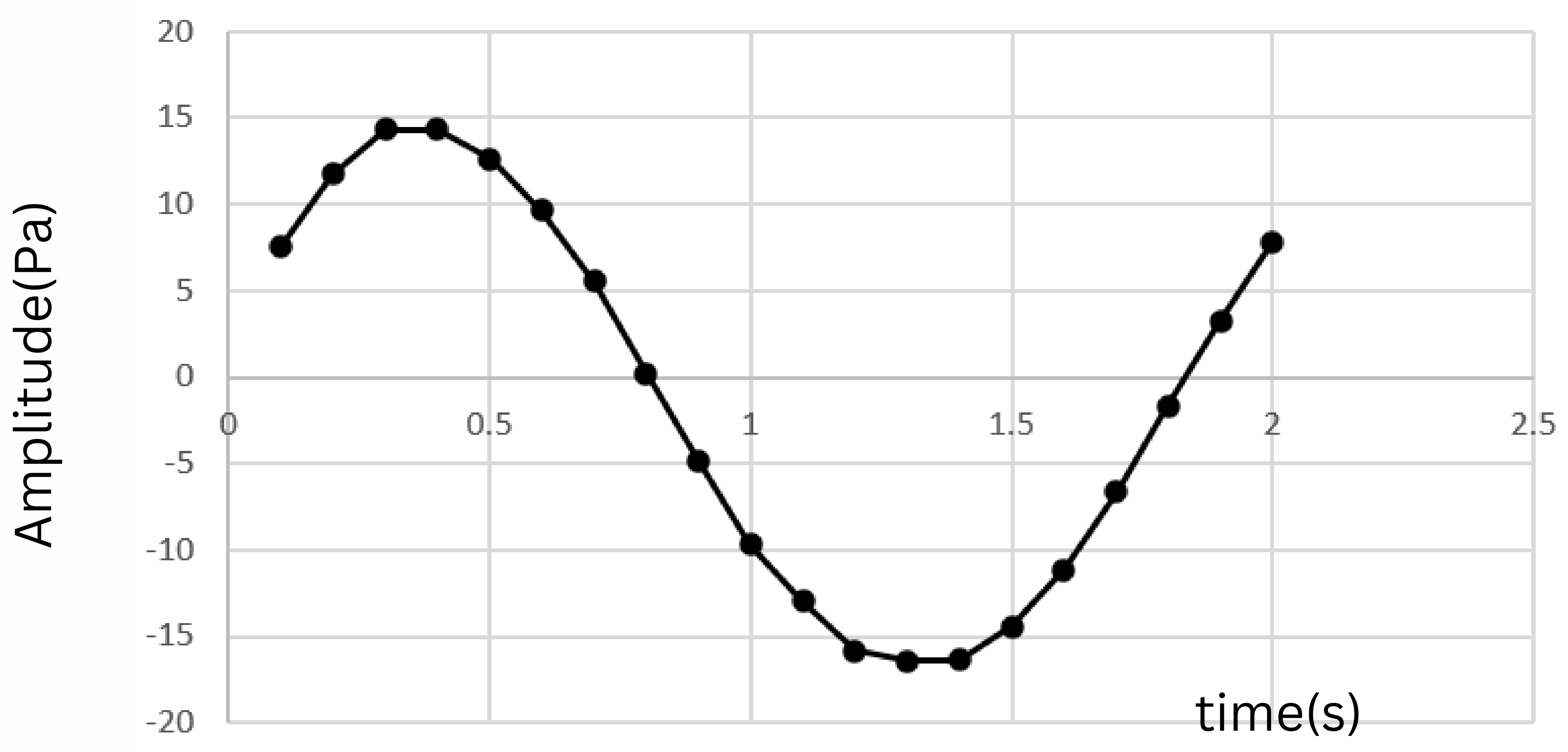
$$\Upsilon = \Upsilon_o sin(\varpi t)$$

Input sinusoidal curve:

$\Upsilon_o = 0.005$

$f = 0.5$ Hz

Stress (Output)



$$\sigma = \sigma_o sin(\varpi t + \phi)$$

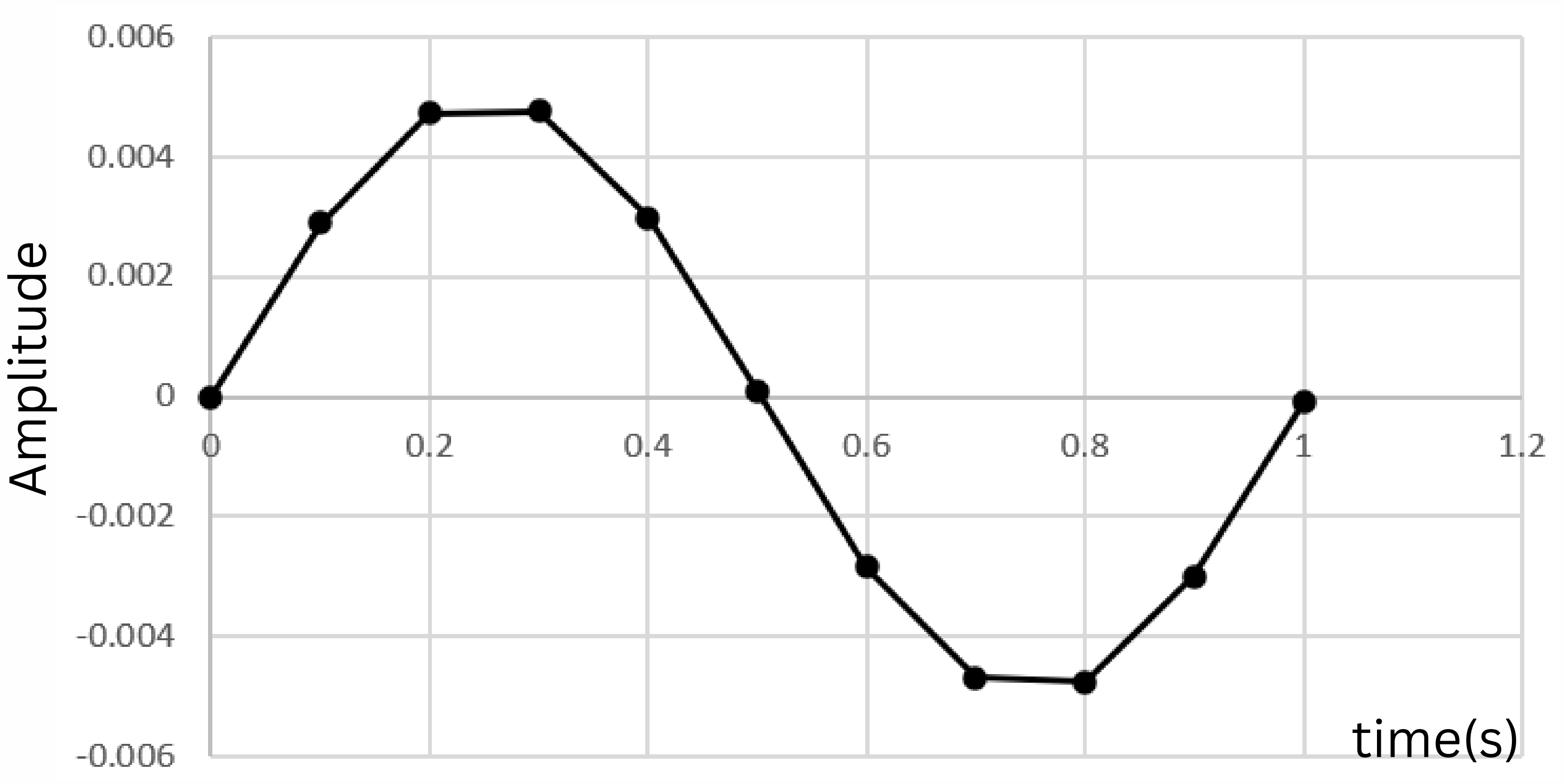
Best Fit sinusoidal curve:

$\sigma_o = 15.529$ Pa

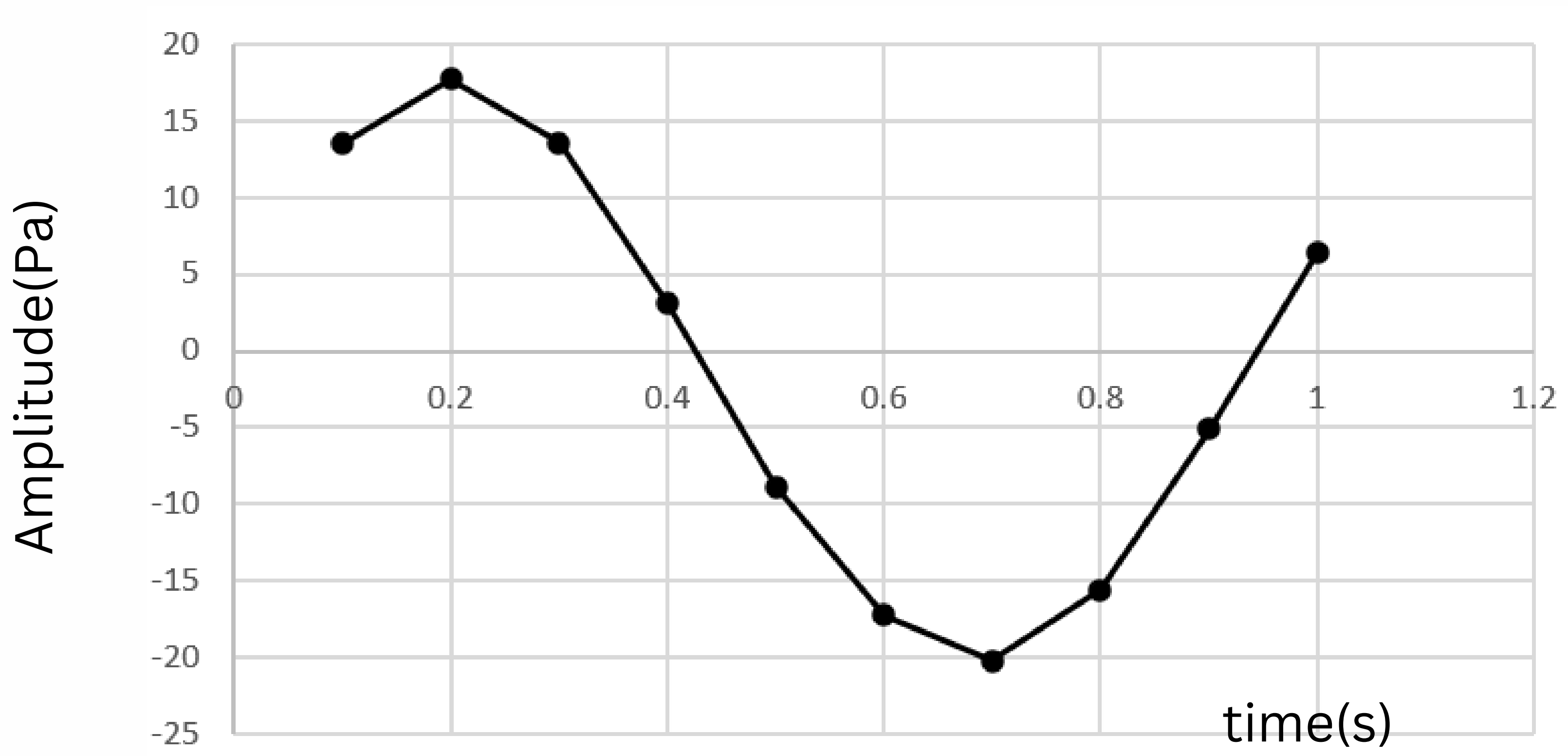
$\phi = 0.370$ rad

DATA 4

Shear Strain (Input)



Stress (Output)



$$\Upsilon = \Upsilon_o sin(\varpi t)$$

Input sinusoidal curve:

Υ_o = 0.005

f = 1 Hz

$$\sigma = \sigma_o sin(\varpi t + \phi)$$

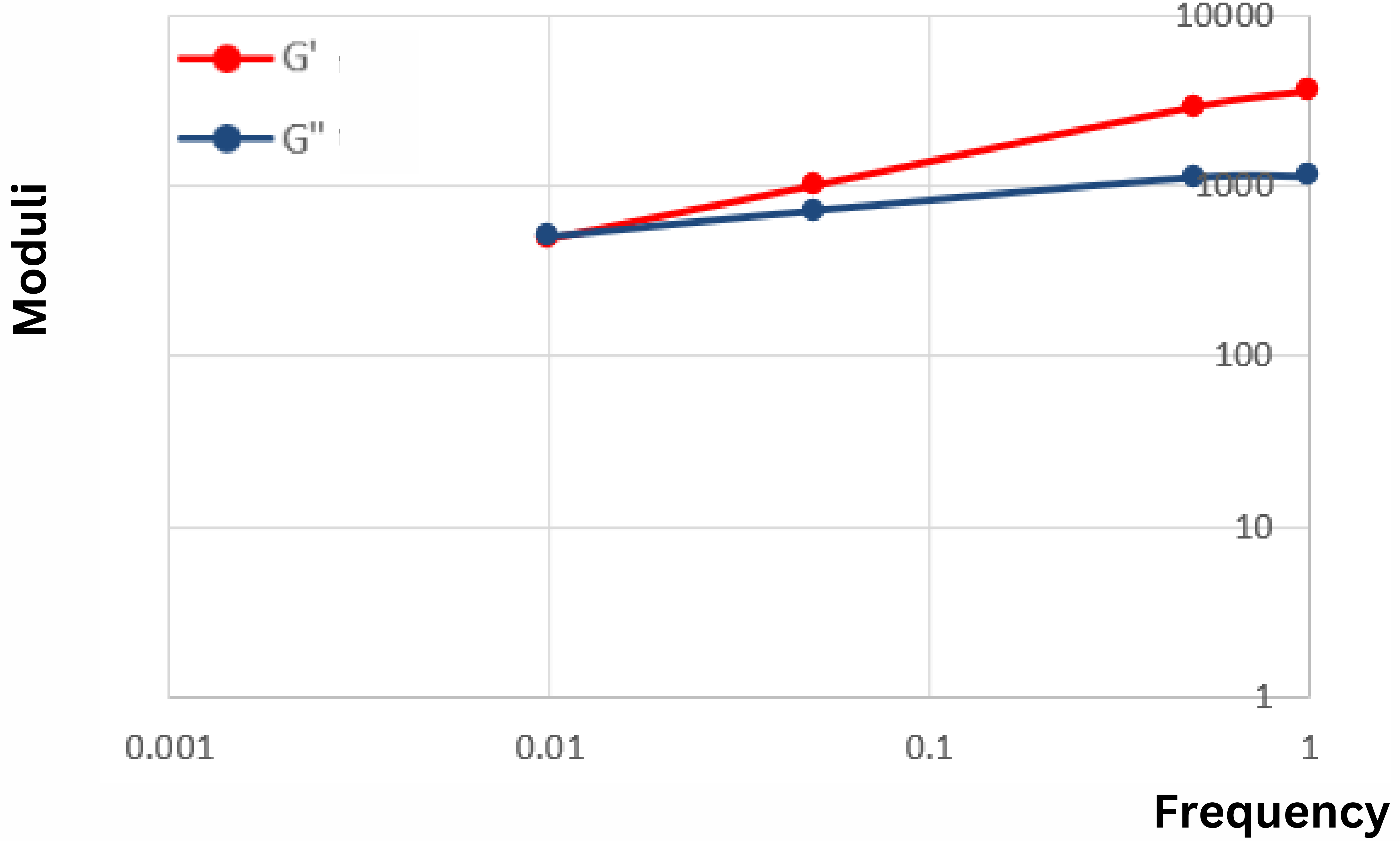
Best Fit sinusoidal curve:

σ_o = 18.822 Pa

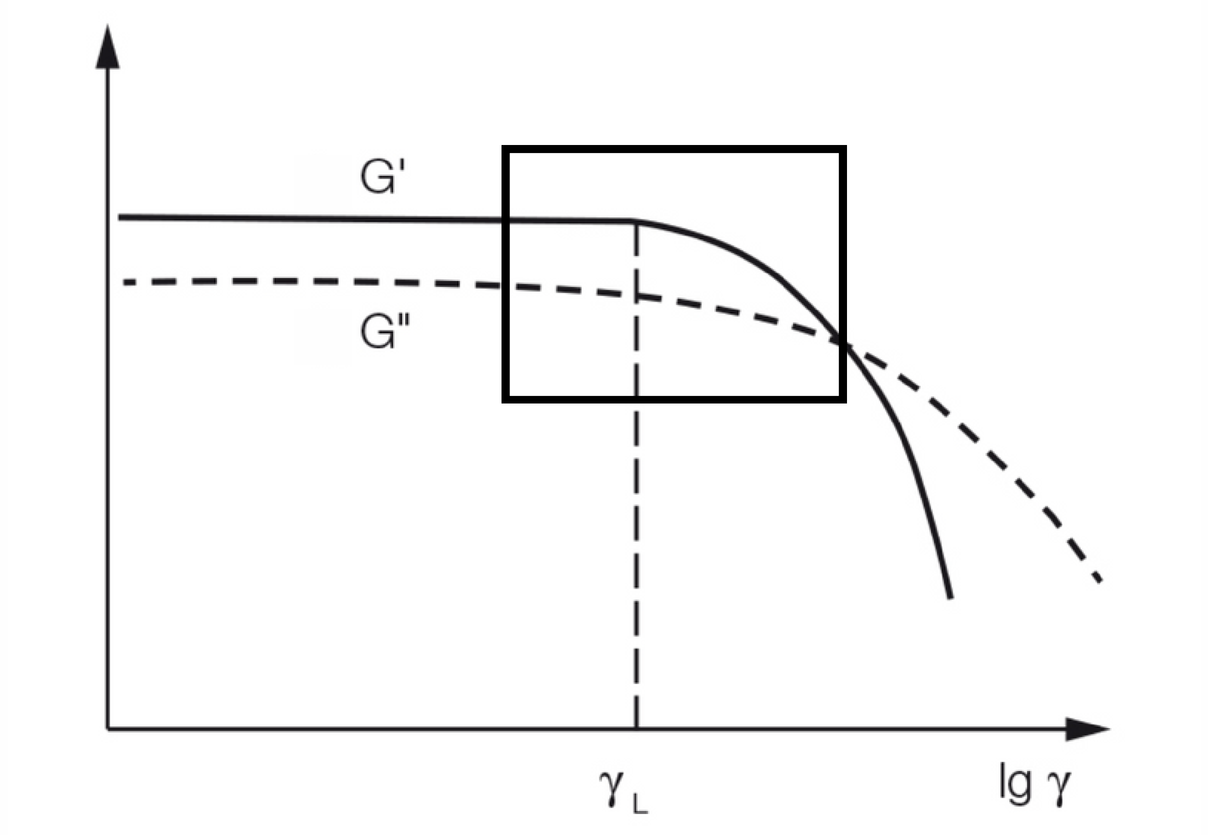
ϕ = 0.308 rad

G' AND G''

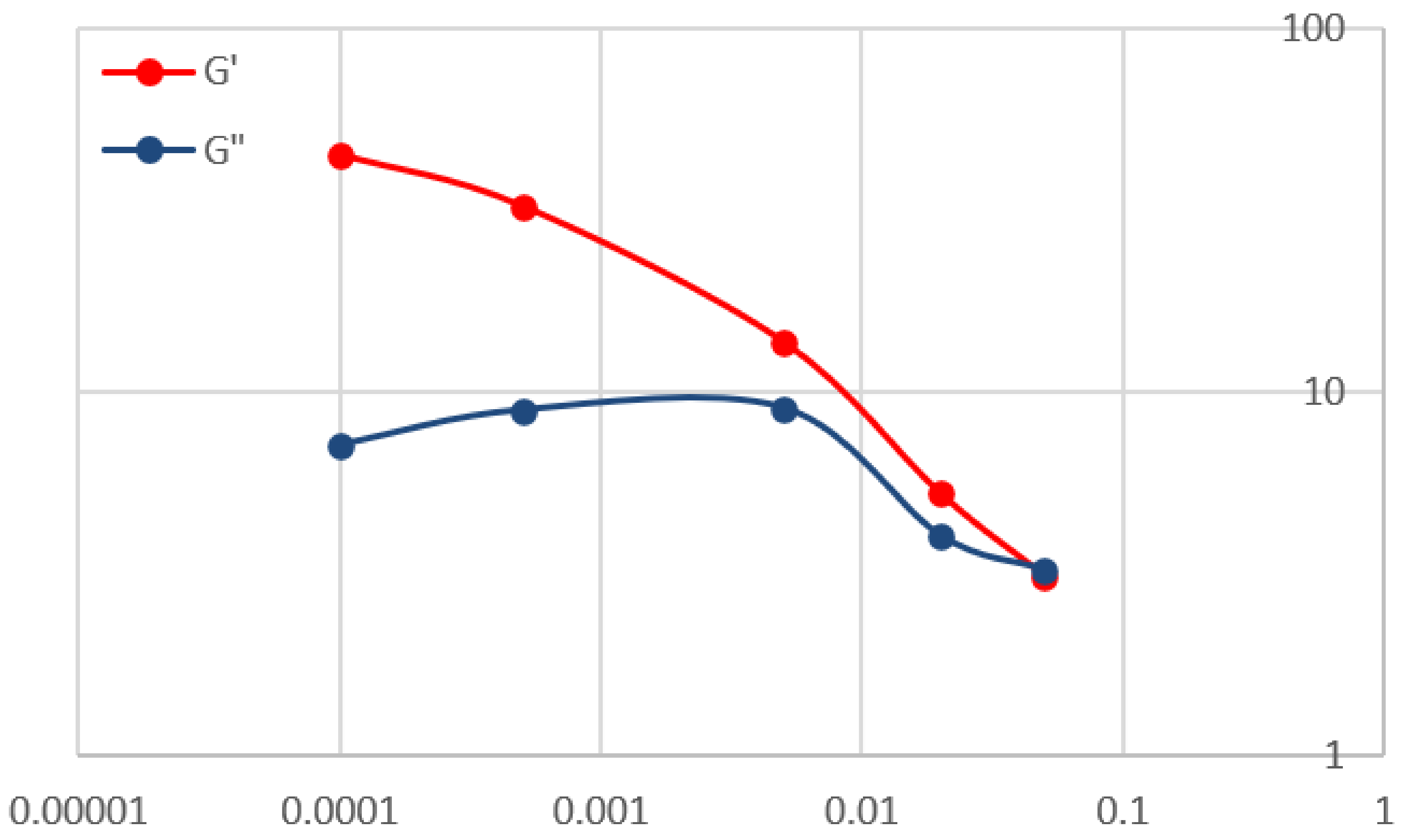
γ_o	f Hz	G' Pa	G" Pa
0.005	0.01	487.94	498.02
0.005	0.05	1004.1	710.90
0.005	0.5	2894.9	1124.99
0.005	1	3587.1	1142.22


G'
G''
10000
1000
100
10
1
0.001
0.01
0.1
1
Moduli
Frequency

RESULT AND CONCLUSION

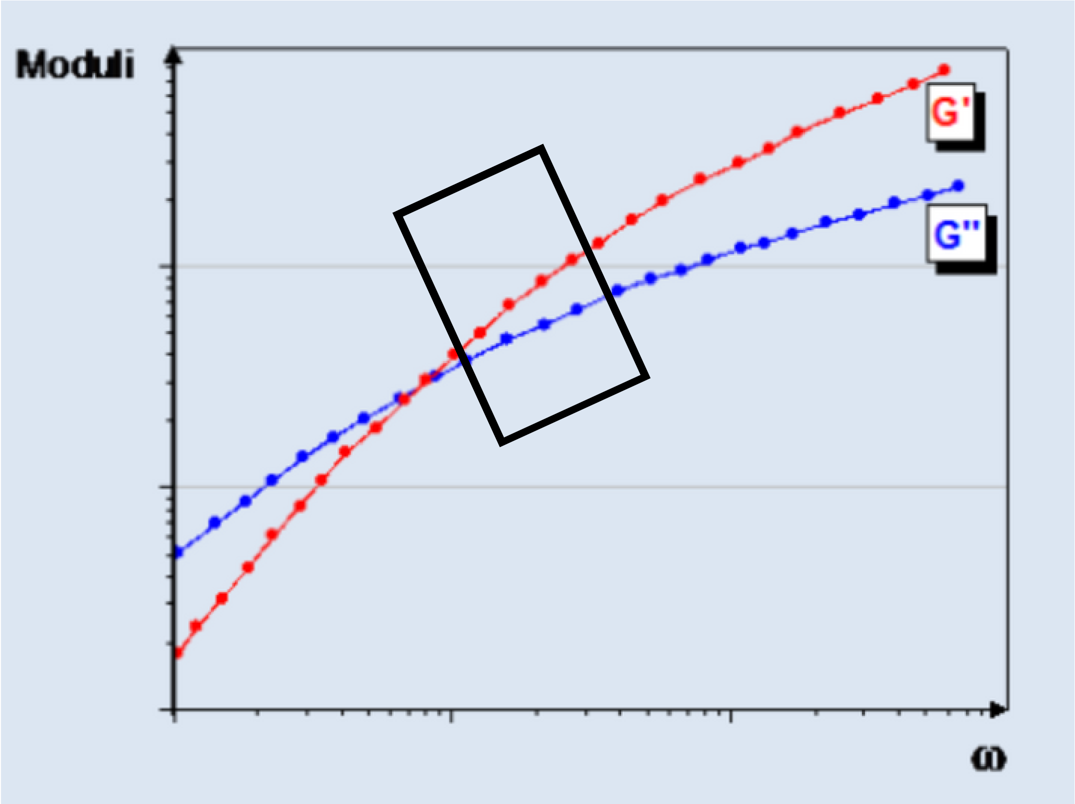


Moduli Vs Strain Amplitude

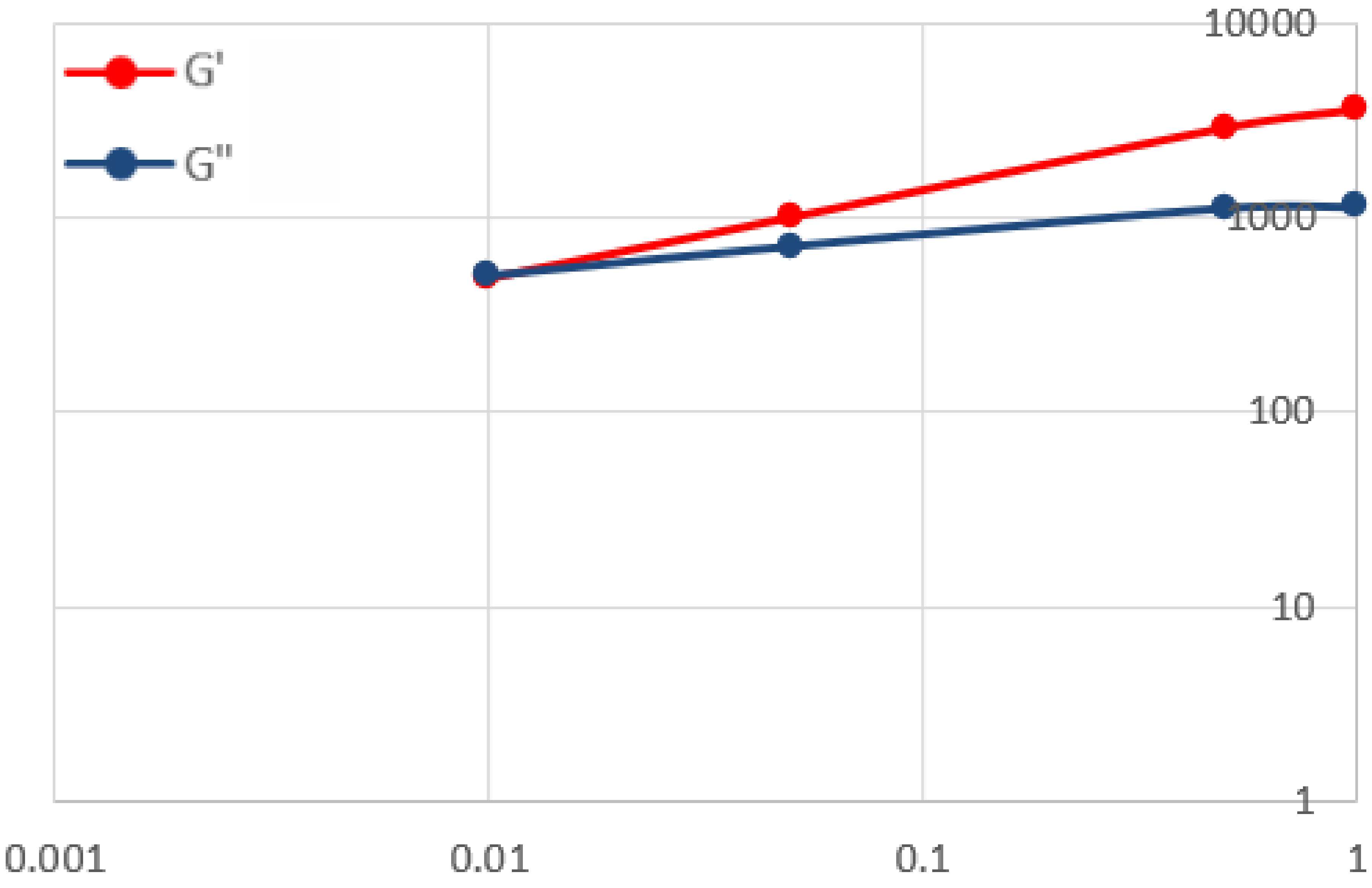


Moduli Vs Strain Amplitude

RESULT AND CONCLUSION



Moduli Vs Frequency



Moduli Vs Frequency

THANKYOU!