A stiffness-controllable joint using antagonistic actuation principles

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1. Introduction and background

Background:

☐ A vital branch in the field of soft robotics aims to develop inherently safe collaborative robots for human-robot interaction.

☐ Although, some concepts of soft actuators [1], joints [2] or manipulators have been proposed to contribute in this fields, there still are some critical gaps.

Critical Gaps:

☐ The **antagonistic actuation behavior** for this type of soft joint has not been evaluated experimentally.

☐ The **dimensions, structure, and controlling strategies** of existing concepts are not specially designed and optimized for being a joint for collaborative robots.

☐ The **percentage of the soft material** is not high enough to have the inherent safety.

Aim of this work

To find out how to utilize the novel stiffness controllable joint to replace the traditional joint of the collaborative robot, creating inherent safe human-robot interaction.

1. Design and Prototype

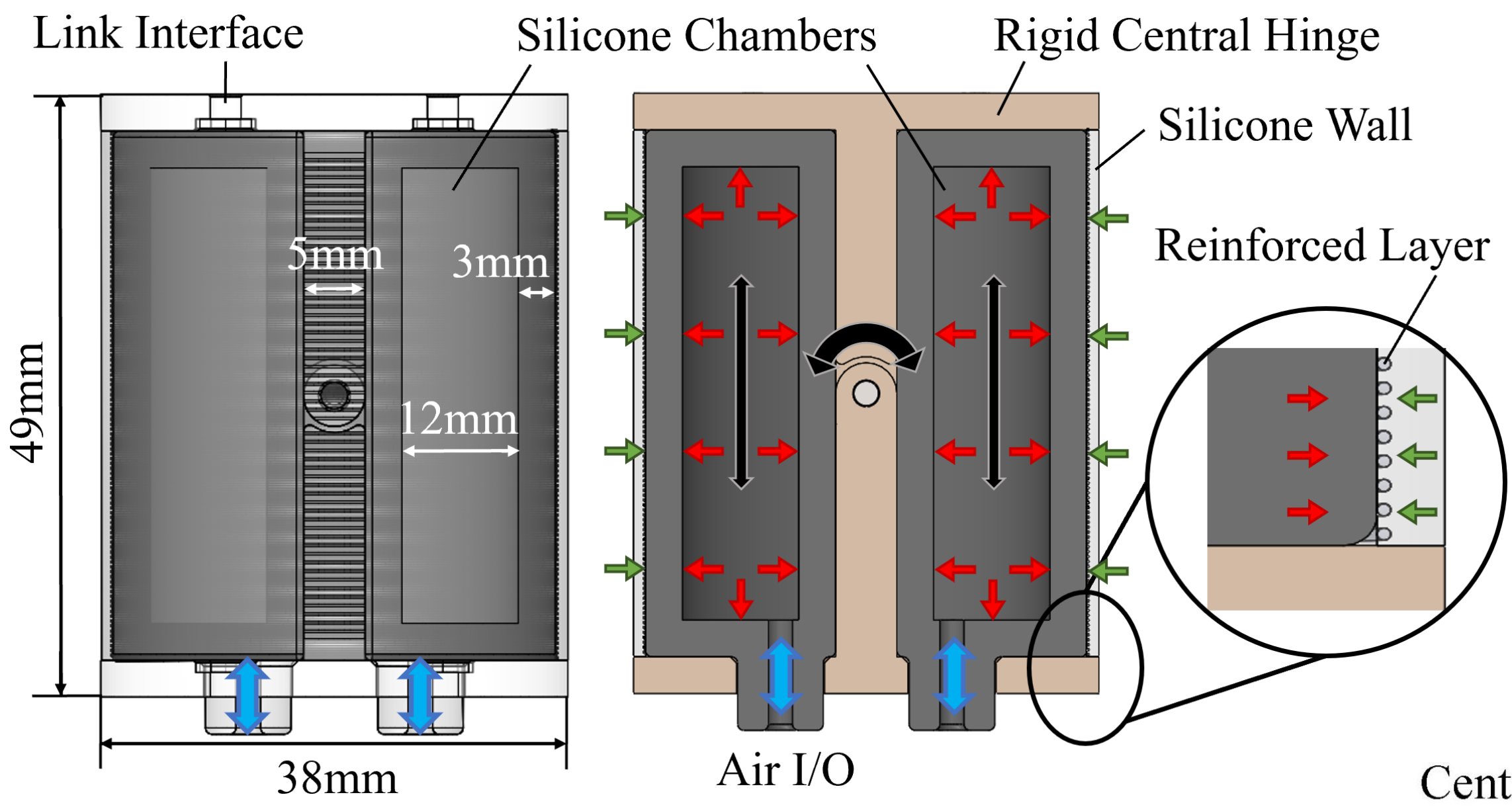


Figure 1: Design and working principle of the joint prototype

☐ Design

Two silicone chambers are located in the both sides of the rigid central hinge and fiber reinforced layer is surrounded with joint.

☐ Prototype

The diameter of the joint prototype is 38mm and the height is 49 mm, which achieve around 100 degrees bending angle.

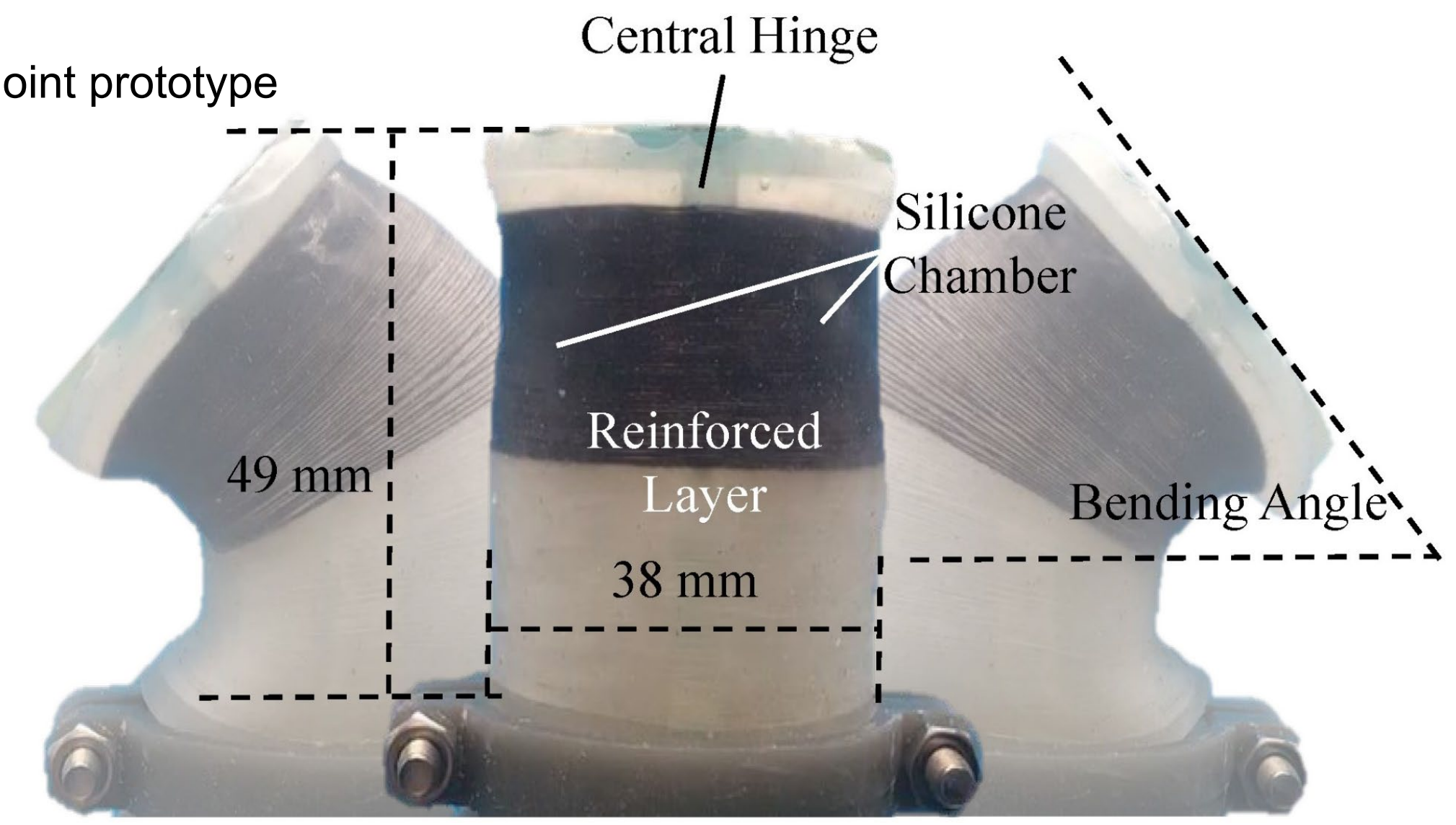
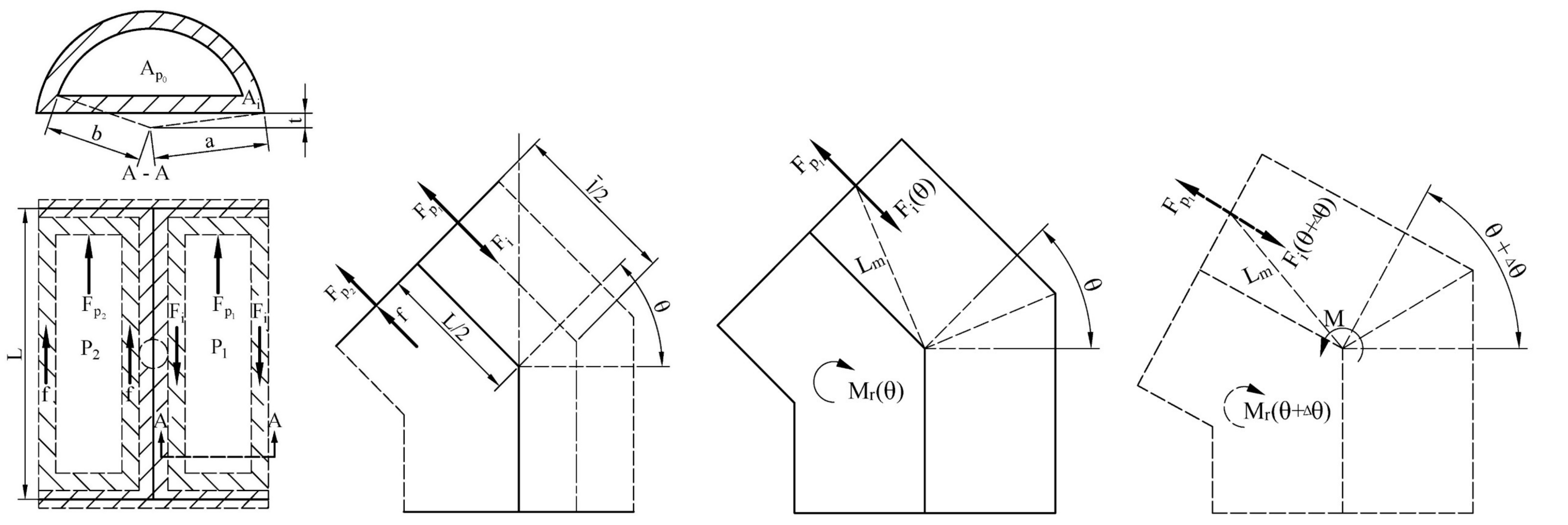


Figure 2: Overview of the joint prototype.

2. Modeling

☐ Simplified geometric model



☐ Kinematic model

Explicit Relationship

$$n_0(P_1^2-P_2^2)+A_{p_0}(\boxed{P_2-P_1}) = A_i\bar{u}\left(1+\frac{a}{L}tan\left(\boxed{\frac{\theta}{2}}\right)-1/\left(1+\frac{a}{L}tan\left(\frac{\theta}{2}\right)\right)^3\right)+n_1\theta^{n_2}$$

☐ Stiffness model

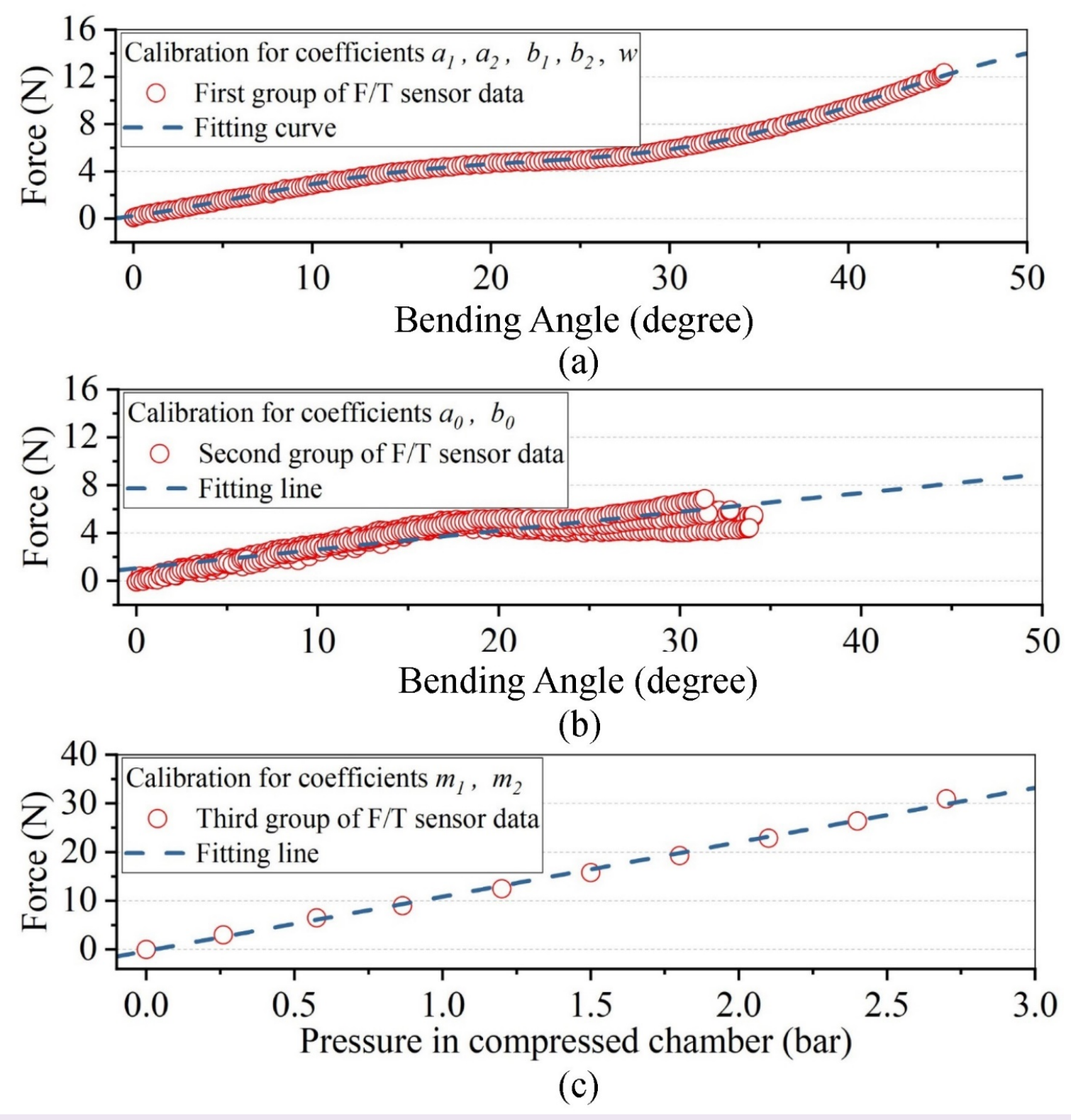
$$K(\theta)=\frac{M_r((\theta+\Delta\theta),P_c)-(F_{p_1}-F_i(\theta+\Delta\theta))L_m}{\Delta\theta},$$

$$M_r(\theta,P_c)=M_r(\theta)+M_r(P_c).$$

$$M_r(P_c)=\frac{1}{2}(m_1P_c+m_2)L,$$

$$M_r(\theta)=\frac{1}{2}(a_0+b_0\theta+\sum_{n=1}^{2}(a_ncosw\theta+b_ncosw\theta))L,$$

☐ Coefficients Calibration



3. Experiments and Results

☐ **The bending angle evaluation:** Use the Aurora 3D Tracking system to measure the bending angle when the prototype (shown in figure 2) is actuated by the servo vale system.

☐ **The variable stiffness evaluation**: the stiffness of prototype is evaluated by the linear rail, F/T sensor, Aurora 3D Tracking system and 7-Axis Collaborative Robot shown in figure 3.

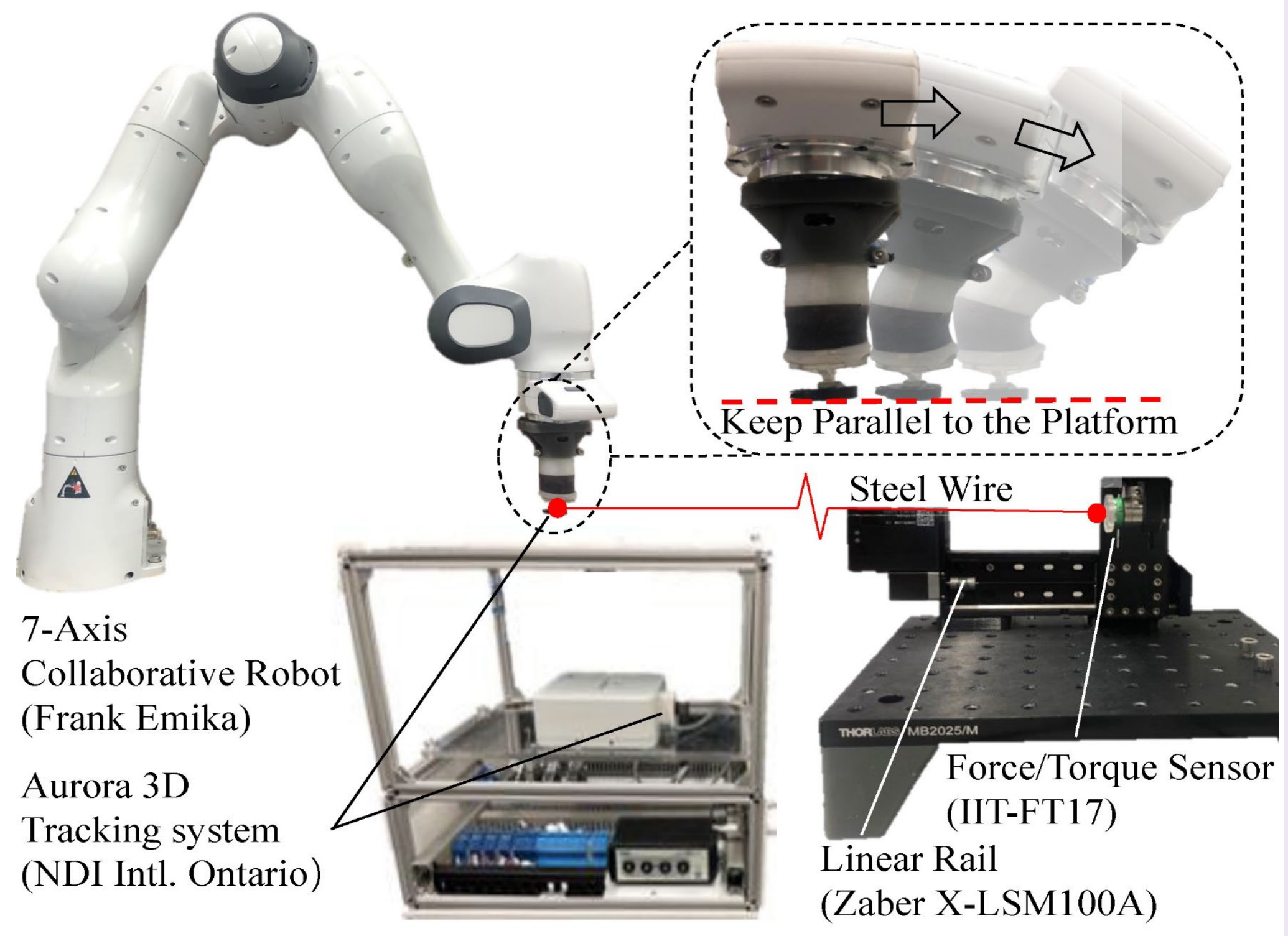
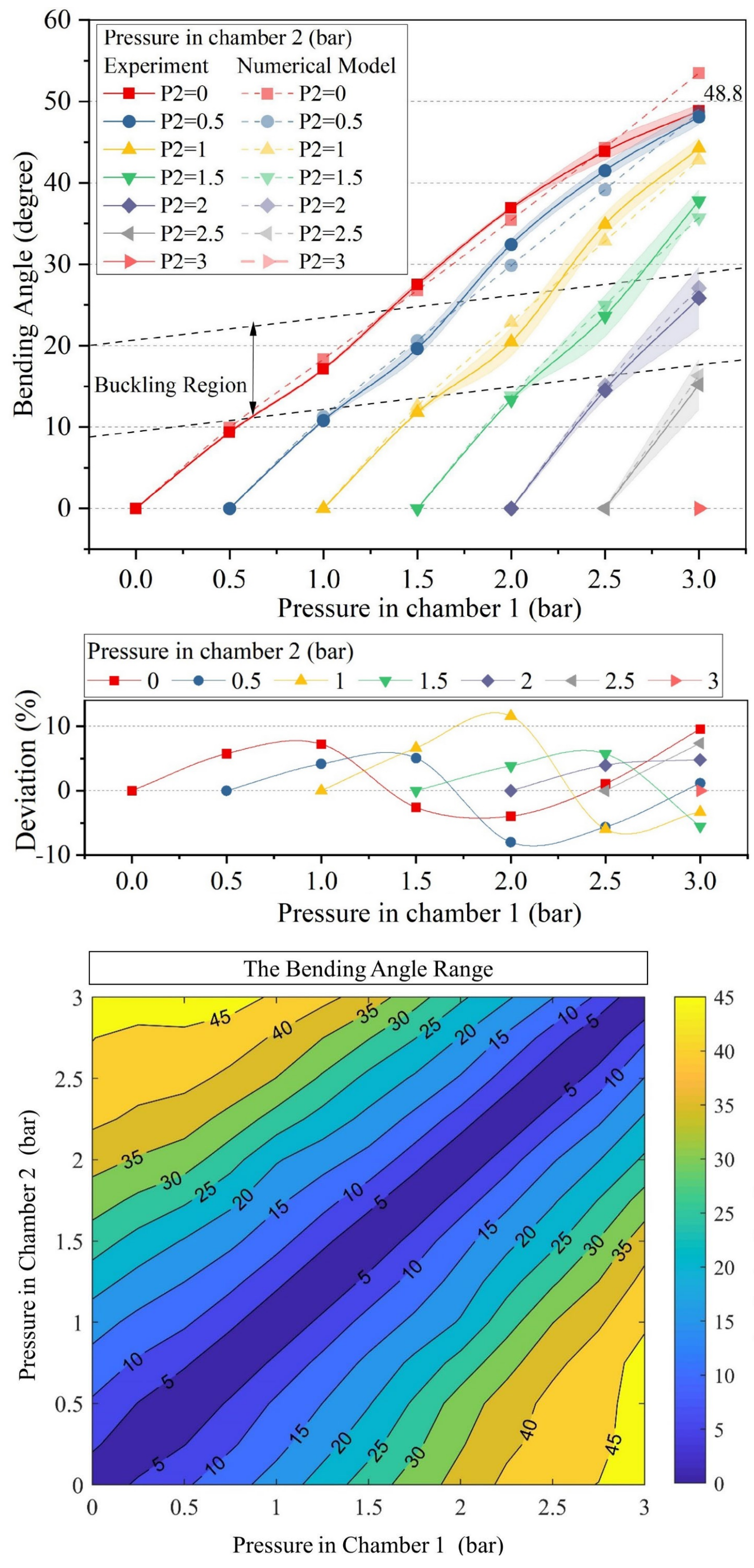
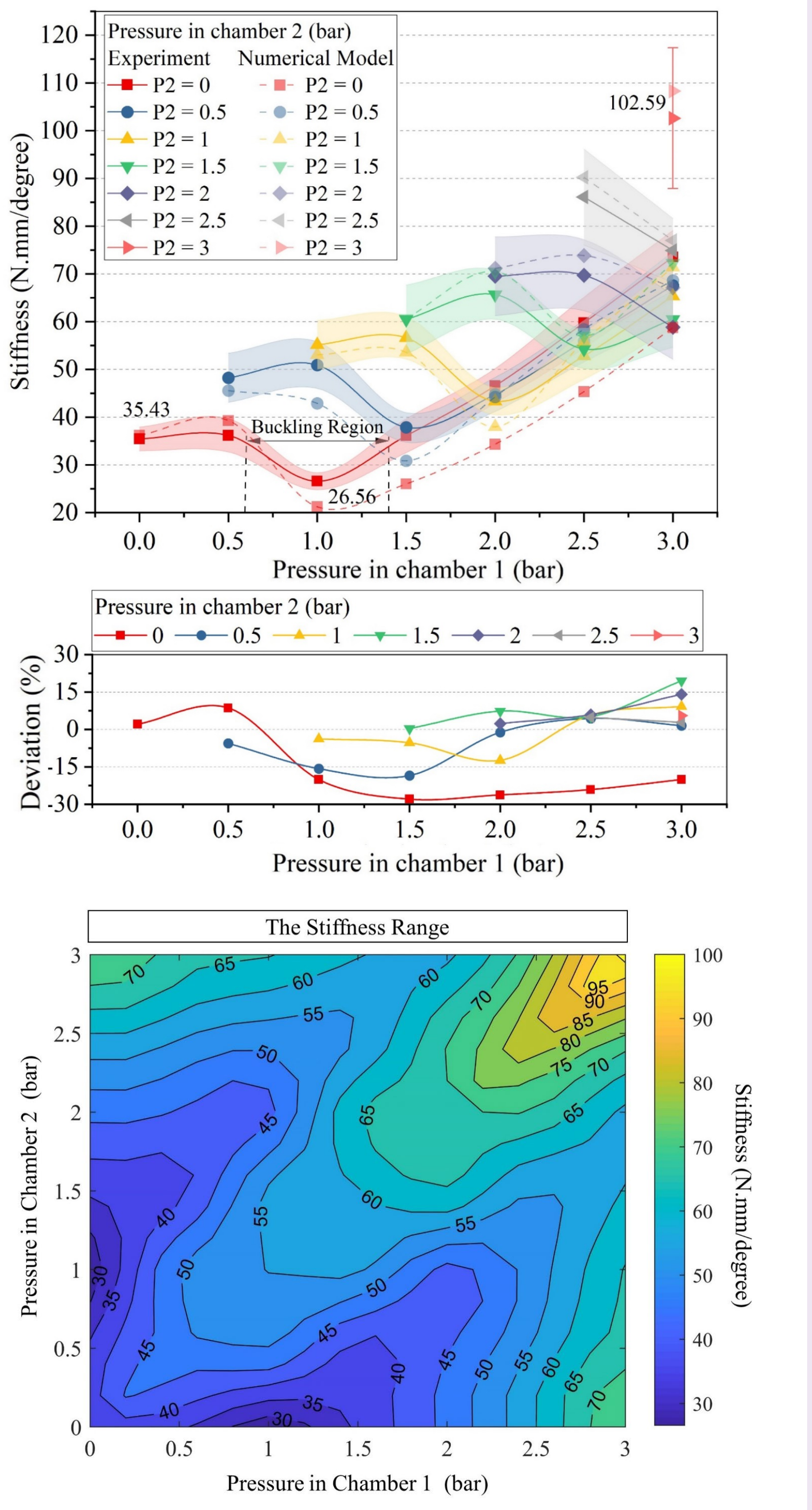


Figure 3: Experiments setup.

☐ Bending Angle Result



☐ Stiffness Result



4. Conclusions

☐ The joint has the wide **variable stiffness range** (i.e., from **26 to 102** N.mm/degree) benefited from the antagonistic actuation principle.

☐ The joint can achieve **48.79 *degree*** bending angle (on one direction) with a **compact structure and dimensions** which is suitable for being a collaborative robot joint.

☐ The joint made by **over 80% soft material** benefiting for the inherently safe human-robot interaction.

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