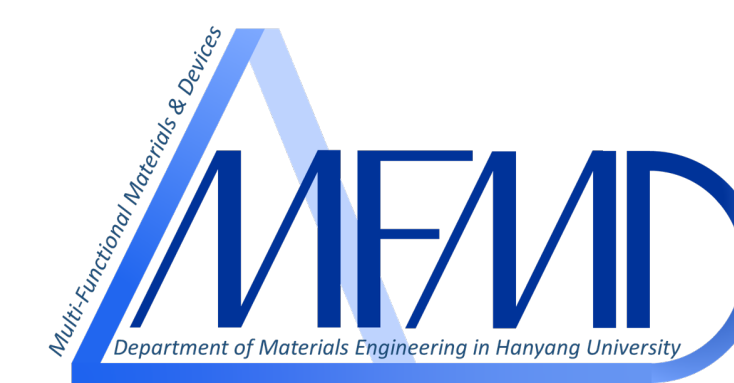


Gender-based Physical Evaluation of Soft Skin for the application of Collaborative Robot



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(SDG goal number 9 : Build resilient infrastructure, promote sustainable industrialization and foster innovation)



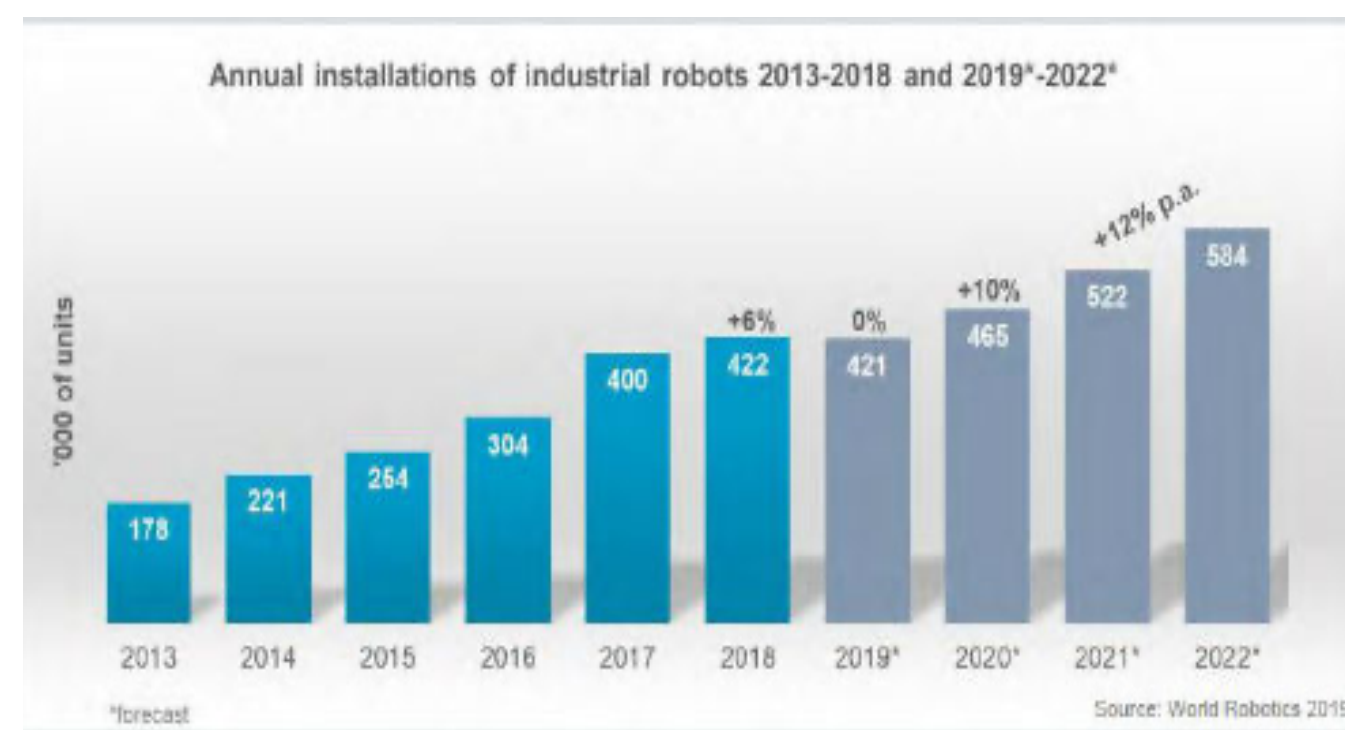
Introduction

§ Industrial Robots

- Numerous robots are located in the industrial site. In particular, due to its nature of the electronics production process, it requires simple repetition with delicate hand technology
- Since industrial robots repeatedly and continuously move, based on coded activities, they operate only in a safety cage and are difficult to use in the same space as humans.

§ Application of Co-bot

- Cooperative robot can physically interact with people while working in the same space as people are.
- Robots are responsible for simple and repetitive manual tasks while people respond flexibly to emergencies.
- Therefore, efficiency of the work can go up by minimizing manpower while maximizing productivity of the robot itself.



§ Touch and emotional discomfort

- Unexpected contact or collision with cooperative robot can cause worker injuries or discomfort during collision.
- Collisions between robots and humans frequently occur, and this lead to human injury or death.
- Cooperative robot is currently coded to prevent such a collision, but most of the robots currently in use are not equipped with such coding system.
- Therefore, our goal is to prevent any type of collision between workers and cooperative robots by reducing any discomfort through overlaying soft skins on industrial cooperative robots and solve the urgent problems; to achieve goal 9 of UNSDGS.
- Since the measure of discomfort when in contact, varies from person to person, criteria for generalization is necessary.
- The criteria was selected by gender and age of around 24 years old.

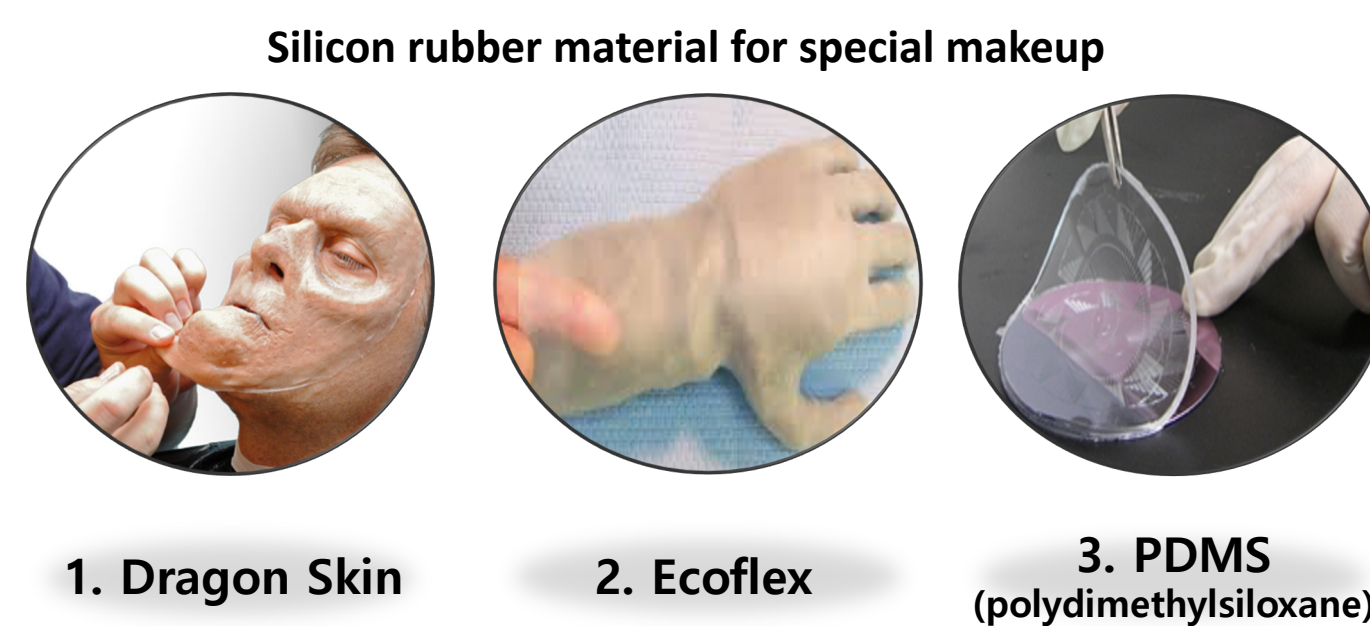
Objectives

- Manufacture Soft Robot skin based on evaluation of polymer material properties and emotional evaluation
 - Selection of materials suitable for robot skin production.
 - Conduct preference survey according to age and gender.
 - Adhesion measurement through contact angle test.
 - Measure elasticity of material through compressive creep test.

Materials selection & preparation

§ Materials selection

- Requirement**
 - Harmless
 - Stretchable material for shock absorption
 - Material that does not smell strongly



§ Procedure for materials preparation

Materials	Preparing
Dragon Skin® (Dragon Skin® 30)	1. Mass ratio 1:1 = Part A : Part B (Part A : main source, Part B : hardner) 2. Dry for 24 hours at room temperature after mixing 3. Curing
Ecoflex® (Ecoflex® 00-30)	1. Mass ratio 10 : 1 = Sylgard A : Sylgard B 2. Dry for 24 hours at room temperature after mixig 3. Curing
PDMS (Sylgard 184)	1. Mass ratio 10 : 1 = Sylgard A : Sylgard B 2. Dry for 24 hours at room temperature after mixig 3. Curing
❖ Curing Condition - Dragon Skin, Ecoflex : 2 hours for 80 °C -> 1 hours for 100 °C - PDMS : 45 minute for 100 °C	

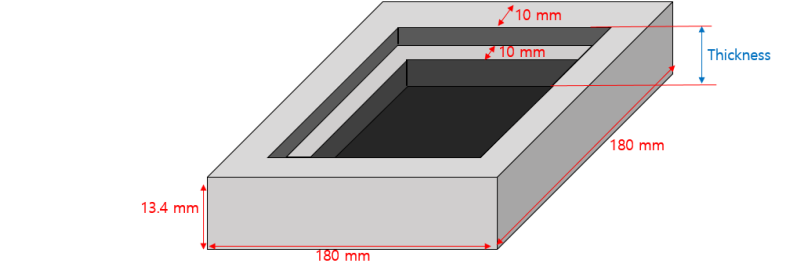
Experimental Details

§ Preference Survey

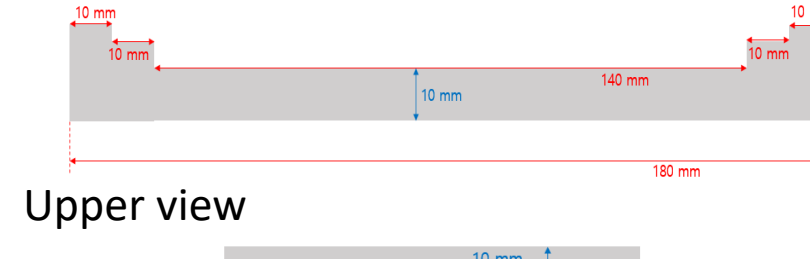
• Samples

> Teflon mold for Sample

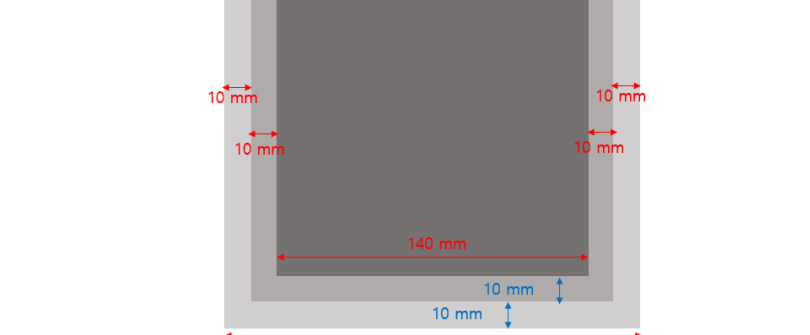
Front view



Side view



Upper view



> Sample thickness

1	3.4 mm Ecoflex
2	7.0 mm PDMS
3	10 mm Dragon Skin
4	3.4 mm PDMS
5	7.0 mm Ecoflex
6	3.4 mm Dragon Skin
7	10 mm Ecoflex
8	7.0 mm Dragon Skin
9	10 mm PDMS

> Sample picture



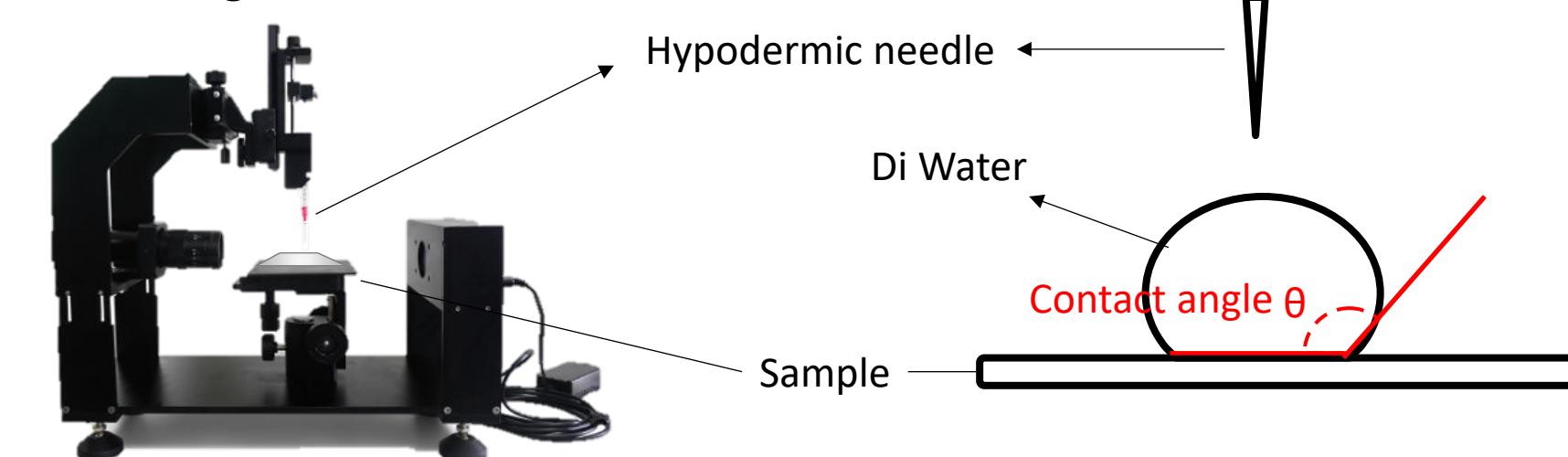
> Survey details

	Male	Female
Over 24 (24-32)	50	45
Under 24 (18-23)	75	62

- The preference survey was conducted for total **232** people whose ages ranged from 18 to 32 years old.
- Attendees for survey were composed of **125** males and **107** females.
- Number of male under 24 was **75** and over 24 is **50**.
- Number of female under 24 was **62** and over 24 is **45**.
- The scale of survey ranged from -5 to +5 depending on stiffness, stickiness, familiarity and preference.

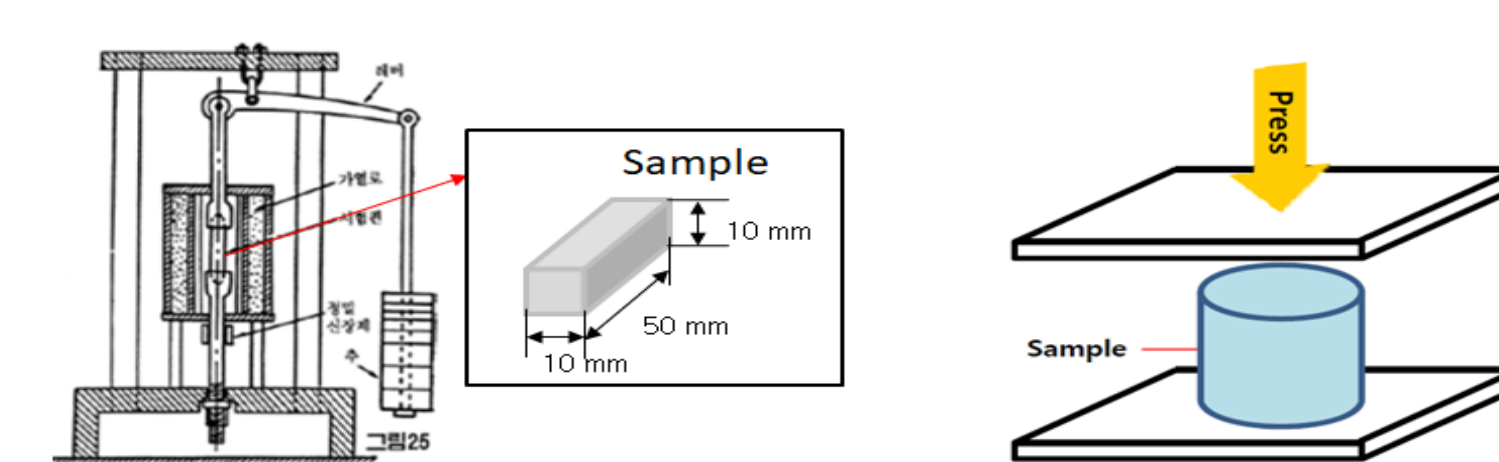
§ Physical property measurement

> Contact angle test



- After dropping a droplet onto a solid surface, measure the angle between the droplet and the surface.
- Higher the surface tension of the solid surface, smaller the contact angle, and smaller the contact angle, greater the hydrophilicity and better the wettability and adhesion (ASTM D5946).
- Therefore, higher contact angle has less stickiness while lower contact angle indicates more stickiness.

> Compressive Creep test

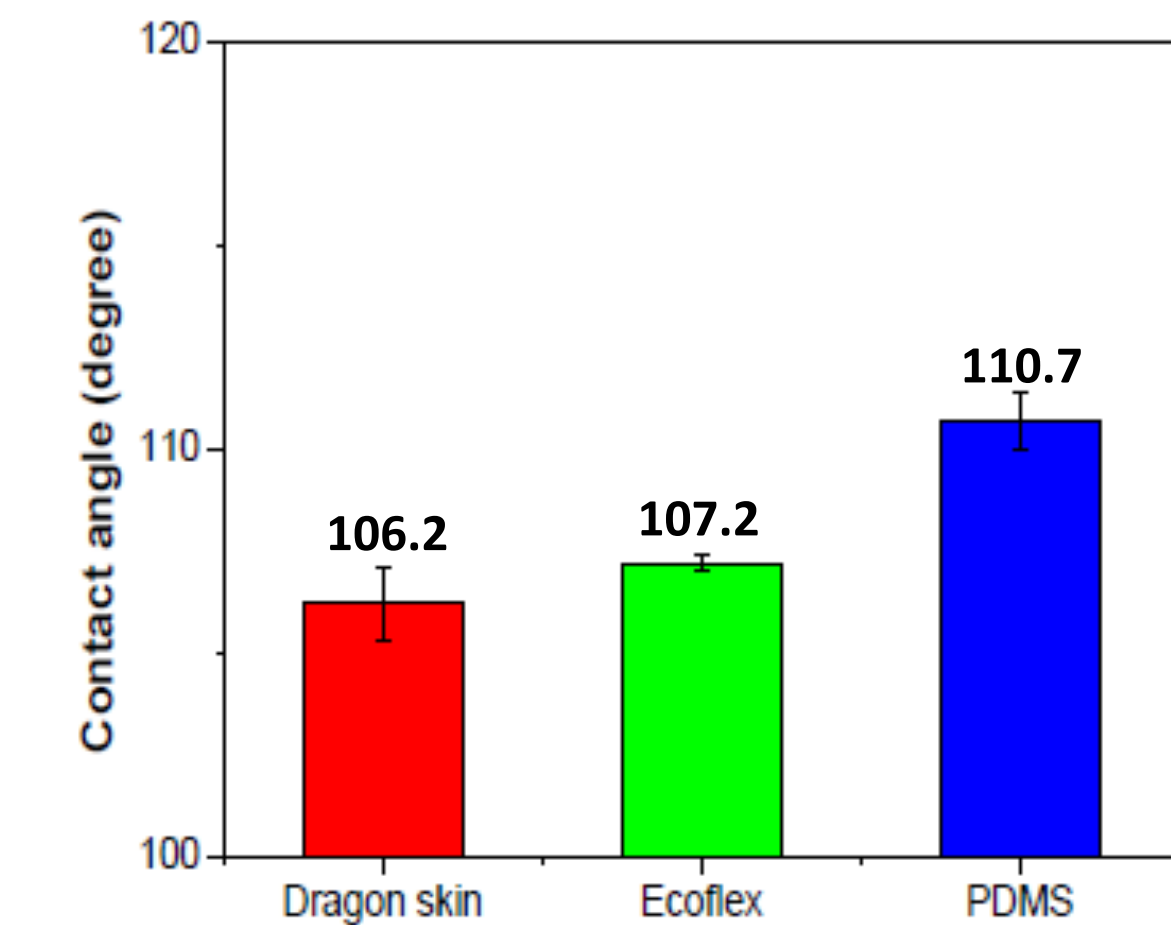


- Press and release the sample with a constant force to measure how much each sample deforms and recovers.
- Each 100% material sample was measured for recovery according to ASTM D 2632-15 Standard.
- The larger the strain, the softer the sample.
- It can consider as stiffness.

Result

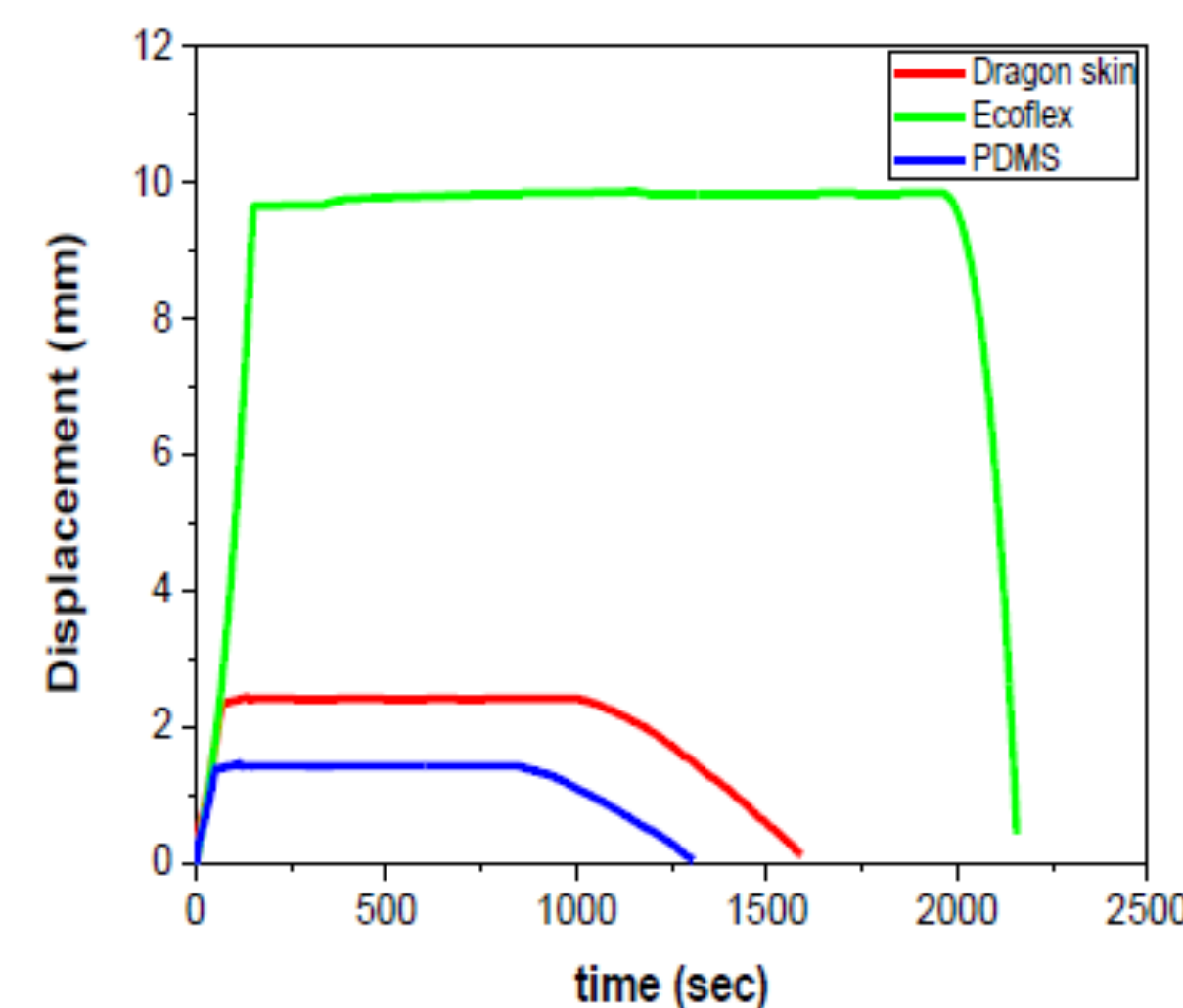
§ Physical property measurement Result

> Contact angle



- Contact angles for Dragon skin, Ecoflex and PDMS are 106.2, 107.2 and 110.7 degrees respectively.
- The largest contact angle sample is PDMS while the smallest contact angle sample is Dragon skin
- For this result, the most sticky sample is Dragon skin while the least sticky sample is PDMS

> Compressive Creep test



- Compressive Creep test was kept under the condition where retention strength is kept 150 N for 30 min. while the resilience for 15 min.
- The largest deformed sample is Ecoflex and the least deformed sample is PDMS.
- For this result, we can know that the stiffest sample is PDMS and the least stiff sample is Ecoflex

§ Preference Survey Result

> Tendency of preference regarding physical property

		Male	Female
Shoulder	Over 24 (24-32)	Stiffness ↑, Familiarity ↓ ⇒ Preference ↑	Stickiness ↓, Familiarity ↑ ⇒ Preference ↑
	Under 24 (18-23)	Stickiness ↓, Familiarity ↑ ⇒ Preference ↑	Stickiness ↓, Familiarity ↑ ⇒ Preference ↑
Elbow	Over 24 (24-32)	Stiffness ↓, Stickiness ↑ ⇒ Preference ↑	Stiffness ↑, Stickiness ↓ ⇒ Preference ↑
	Under 24 (18-23)	Familiarity ↑ ⇒ Preference ↑	Familiarity ↑ ⇒ Preference ↑

> Preferred materials by gender & age

		Male	Female
Shoulder	Over 24 (24-32)	3.4 mm Dragon skin	3.4 mm PDMS
	Under 24 (18-23)	7 mm, 3.4 mm PDMS	10 mm Dragon skin
Elbow	Over 24 (24-32)	10 mm Ecoflex	3.4 mm Dragon skin
	Under 24 (18-23)	10 mm PDMS	10 mm Dragon skin

- The table is the result of the preference survey based on male and female, age and physical properties.
- According to the results of physical property measurement and survey results, the most preferred substances by gender/age are shown as well.
- Based on the analysis of the survey, people tend to prefer materials which are less sticky and stiffer.

> Preference score based on gender and point of body contact

Preference (# people)	Male (125)		Female (107)	
Sample	Shoulder	Elbow	Shoulder	Elbow
3mm EF	5.6452	6.0000	4.7129	5.6832
7mm EF	6.6210	6.2984	6.3663	6.4554
10mm EF	6.6774	7.1129	6.4554	6.9010
3mm DS	6.7419	6.4839	6.4356	6.3960
7mm DS	6.0000	6.8065	4.7525	5.5842
10mm DS	6.5000	6.4194	6.0792	6.4752
3mm PDMS	6.7984	7.2823	5.9010	6.2376
7mm PDMS	6.8549	6.7742	6.3861	6.6535
10mm PDMS	6.7339	6.9597	6.5446	6.7822

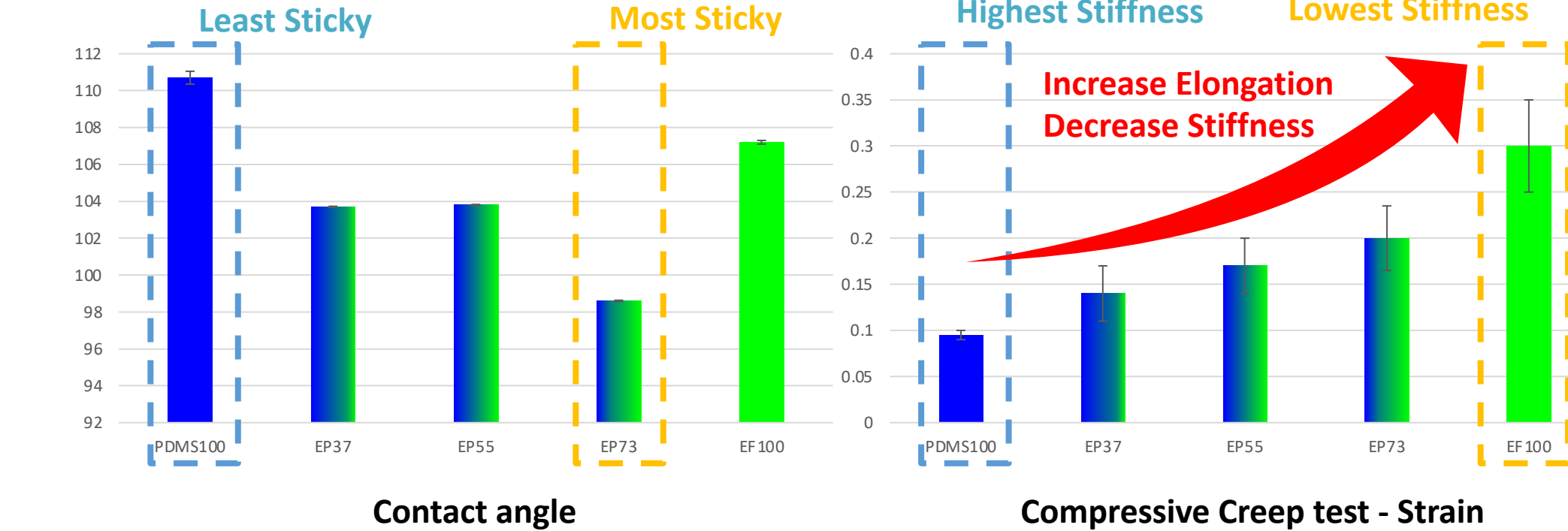
> Preference score based on point of body contact only

Preference	Shoulder	Elbow
3mm EF	5.22669	5.85778
7mm EF	6.506635	6.368858
10mm EF	6.577744	7.017794
3mm DS	6.60444	6.444418
7mm DS	5.440017	6.257765
10mm DS	6.311109	6.444418
3mm PDMS	6.395576	6.813326
7mm PDMS	6.644447	6.720022
10mm PDMS	6.64888	6.88003

- The red number indicates the highest preference score while the blue number indicates the lowest preference score based on the analysis of survey.
- In real industry environment, it is difficult to figure out what is the most appropriate materials depending on gender and age since the ratio of male and female is different in various companies as well as the ratio of the age.
- Therefore, we need to reduce variables to figure out the most appropriate materials to be applied in real industry environment.
- Depending on preference score only in point of body contact, contact at shoulder using 10 mm PDMS showed the highest preference score while the contact at elbow using 10mm Ecoflex showed the highest preference score.
- Therefore, we mixed two materials of Ecoflex and PDMS, with varying ratios of 3:7, 5:5, 7:3 to compare the physical properties of mixed samples.

§ Mixed materials

> Ecoflex + PDMS



- For the mixed samples of Ecoflex and PDMS, the least sticky sample was pure PDMS, while the most sticky sample was mixed sample of 7:3.
- It is hard to predict its tendency of contact angle for mixed materials with its different ratio but its tendency of stiffness decreases while its ratio of Ecoflex is increasing.
- In the preference survey mentioned earlier, workers generally prefer materials with less sticky and high stiffness. The most preferred material is 10 mm PDMS sample.
- For the case of PDMS sample, its stiffness is too high so that it is difficult to attach PDMS on the robot especially if its surface of the robot has high curvature.
- Therefore, considering its easiness to attach the coating materials on the curved surface to some extent, the mixture of Ecoflex to PDMS with its ratio of 5:5, would be the most suitable with good stiffness while minimum stickiness is observed.

Future work

- Plan to fabricate mixture of ECOFLEX-PDMS with its ratio of 5:5 with its thickness of 10 mm and come up with idea on how to wrap this materials around robot arm.

Summary & Conclusion

- To prepare for 4th Industry revolution, the soft robot skin should be developed in consideration of the gender, age, and working environment of workers in the same space.
- The material should be harmless to the human and should not have unfavorable smell in use. We have selected the following 3 materials according to those requirement explained above; Dragon skin, Ecoflex, PDMS.
- As a result of preference survey, both males and females preferred 10 mm PDMS when in contact with the robot using shoulders while 10 mm Ecoflex was preferred when in contact with the robot through elbows.
- Since it is difficult to wrap PDMS alone on the curved surface due to its high stiffness, Ecoflex was mixed to modulate the properties to be able to wrap on the curved surface.
- As a result of the measurement, it can be concluded that the mixed sample of Ecoflex:PDMS which is somewhat flexible, while adhesion and stiffness do not deviate much from our desired standards, was determined to be the most suitable material.