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Correlation between the sensorial perception and the descriptive instrumental analysis of two descriptors of orthogonal touch (hardness and tackiness descriptors)

Introduction

The sensations of hardness of a material and the tackiness of its surface are often approached with the touch sense. The difficulty lies in the subjective nature of perception which is specific to each individual. To rationalize and quantify these sensations, and thus individual expectations, a sensorial rating has to be done[1]. This rating can be realized by a group of experts, who are trained to qualify the sensorial qualities, or by a group of naïve people. However these sensorial qualities can also be approached by specific experimental data.

The completion of physical experimental tests can eliminate the subjective character from the rating of the sensation. Thanks to a sufficient amount of correlations with the subjective quotation results, such experimental tests can totally substitute themselves or at least partially for the panel of experts. The research of correlations between sensorial rating with subjective characteristics and instrumental parameters implies that these objective data are obtained with a protocol which precisely reproduces the movement and the associated stimuli of the human tester. This is the main difficulty and it requires dedicated apparatus for each sensation.

This comparative problematic is the aim of the CEMAS actions (Centre d’Evaluation des Microtechniques pour l’Analyse Sensorielle[2]). Its main activities are focused on the assessment related to human senses (sense of touch, sight, hearing, smell and taste) of products or materials and concern:

- the realization of referential samples, which are classified objectively and subjectively;
- the correlation between sensorial notations and the parameters resulting from the instrumental data obtained by specific apparatus;
- the conception, the realization and the commercialization of these different devices which reproduce with high fidelity the sensorial conditions related to subjective human assessments.

The present study concerns the touch sensations of hardness and tackiness, and focuses on the development of instrumental procedures which can be substituted to the sensorial rating resulting from a panel of experts. These two sensations can quantitatively be approached by specific sensorial metrology devices. For this purpose, an instrumented measuring device has been developed. This instrument has the aim to give physical data which measure the stiffness and the tackiness of any samples to be evaluated. As an illustration of the ability of this device to assess this goal some results are presented on two different materials.

Apparatus

An instrumented probe tack test device has been developed in the laboratory and allows to reproduce tactile exploration for the qualification of hardness and tackiness of a material. This apparatus allows to characterize both bulk and surface material properties by indentation experiments[3-6]. Figure 1a presents the design of the testing device. This experimental apparatus allows to do z-axis loading and unloading cycles with probes of different geometrical forms (spherical, cylindrical flat-ended punches,…) and made of various materials (aluminium, steel, glass,…).

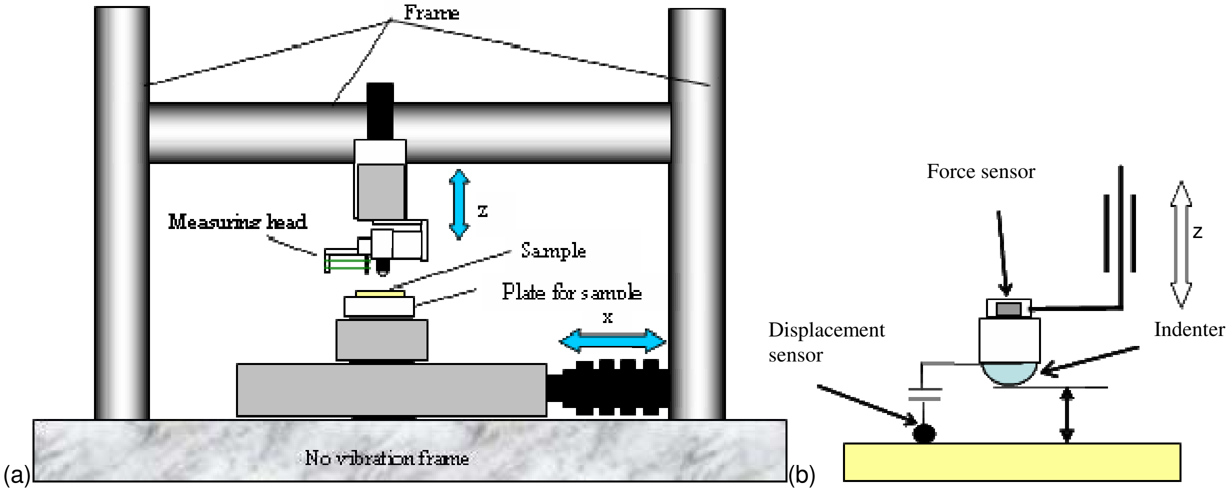


Figure 1: Schematic of the instrumented probe tack test device (a) and the measuring head (b).

The experimental device is made of the following parts:

- Moving tables driven by stepping motors; these tables allow the (x,y) motion of a plate where the sample is fixed;
- A measuring head which allows to drive the probe in the z-motion.

During the penetration of the probe in the material, the measuring head (Figure 1b) allows to measure continuously the normal force F, which is exerted by the sample on the probe, and the depth of penetration δ. This depth is measured relatively to the surface of the material by a differential measure, which allows to determine precisely the depth of indentation: a LVDT sensor measures as accurately as possible the penetration of the probe into the sample. The maximum measuring displacement of this sensor is 1 mm (range of ± 0.5 mm) with a resolution of 0.25 µm. Moreover this measuring head allows to get rid of the compliance of the apparatus: the displacement sensor is kept by two flexible thin blades which introduce a compliance of 12.5 mm/N. This compliance introduces an additional force which has to be corrected during data processing.

The force F is measured by a force sensor placed above the probe, which has a maximum load of 20 N with a 5.35 mN resolution. An electronic low pass filter (f_c = 33.86 Hz) is positioned at the output of the displacement sensor amplifier and the load cell amplifier in order to reduce the noise on the measures.

A National Instrument Labview® application allows to control the stepping motors, the different testing parameters (velocity and depth of the indentation, contact time…) and to collect and process the different data. The experimental results obtained from a test are the force and the displacement as a function of time, and the curve of the force versus the depth (load – unload curves).

Mechanical characterization

An indentation test is a loading – unloading cycle with a controlled velocity. A probe is brought in contact with the sample. After the contact the punch penetrates into the material at a constant velocity up to a preset value (force or displacement value) and remains in contact during the contact time. Then the probe unloads with an identical or different velocity.

The response of the material to the mechanical solicitations supplies information about the mechanical characteristics of the material (Figure 2): the Young's modulus E, the stiffness K, the force F_{adh} and the energy ω_{adh} of adhesion… The adhesion force F_{adh}, or tack force, is the maximum tensile force, while the adhesion energy ω_{adh} is represented by the area under the force-displacement curve normalized by the contact surface. Another parameter which can be interesting to study is the tack distance Δ_{adh}. This parameter corresponds to the distance between the moment when the force is negative and the moment when the probe is completely separated from the sample

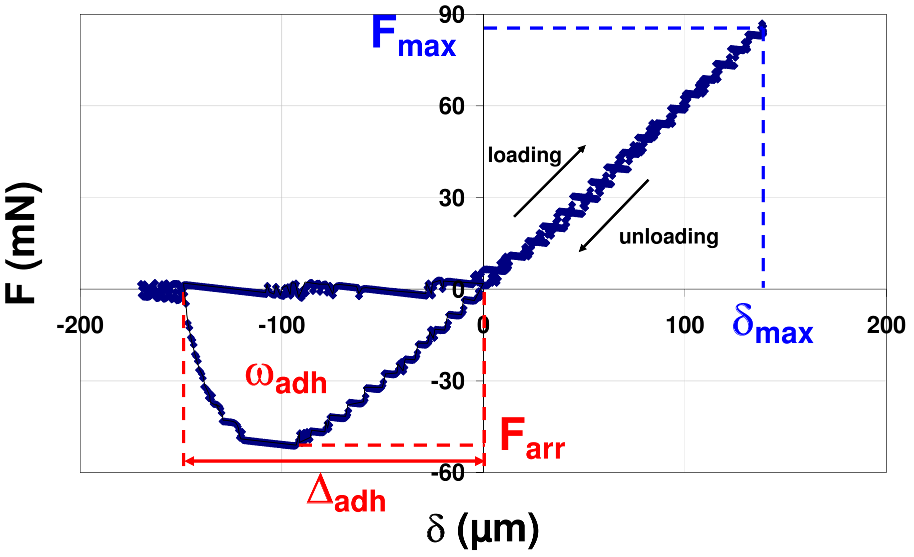


Figure 2: Classical curve of indentation for a sticky elastic material.

Samples

The study of hardness and tackiness properties is realized on different specific materials. Coming from the tactile reference Sensotact®[7], the samples of hardness descriptors are elastomer-like material foams and are composed of eight references: Hardness 10, 30, 50, 75, 90 and 95 (Figure 3). The notion of hardness describes the force which is necessary to penetrate the finger (generally the index) in the material. The protocol is based on an orthogonal pressure of the finger on the sample and the hardness sensation is described by the evaluation of the force which is necessary to lightly penetrate the sample with finger pulp. The more important the exerted force is, the higher the force intensity is; and consequently the sample will be quoted as hard.

Figure 3: Example of samples of hardness descriptors.

Contrary to the hardness descriptors, tackiness descriptors are not stemming from the Sensotact® but are prepared in the laboratory in order to develop the tackiness descriptors. The study of the tackiness is realized on samples of two component RTV (Room Temperature Vulcanization) silicone elastomers. These elastomers crosslink at room temperature and have a natural tackiness. This adhesion is explained by the presence of the free molecular chains resulting from the combination of the reticulation network of the silicone on the one hand, and the lack of reinforcing agent on the other hand. These free molecular chains have free bonding, which can establish covalent bonding, accountable of the adhesive properties. The samples are represented by two types of silicones of 10/12 mm thick: the compact silicones and the gel-like elastomers. These two types of silicones offer a large range of stickiness. The more the force required is, the higher tackiness intensity is.

Hardness sensation	
Sample	Sensorial notation
Dureté 10	10
Dureté 30	30
Dureté 50	50
Dureté 75	75
Dureté 90	90
Dureté 95	95

Tackiness sensation			
Sample		Sensorial notation	Standard deviation
A	RTV 3428	34.5	0
B	Sylgard 184	44.8	+/- 4.5
C	RTV 4411	62.1	+/- 10.4
D	RTV 4528	79.3	+/- 9
E	RTV 4408	89.7	+/- 5.6
F	RTV 4511	100	0

Table 1: Sensorial notations for hardness and tackiness samples.

Sensations of hardness and tackiness of the different samples have been quoted by a panel of experts, who are trained to qualify and to quantity these sensations. The hardness sensation are quoted and are used as sensorial references, while the tackiness sensation are quoted with a first tackiness descriptor (tackiness references 0, 30, 50, 80 and 100) and are brought back on a [0-100] scale. Table 1 presents the hardness and tackiness sensorial notation of the different samples. For more facility tackiness samples are named from A to F. Thus, sample Hardness 95 and sample Hardness 10 have respectively the higher and the lower hardness sensations, while RTV 4511 has the higher and sample RTV 3428 the lower tackiness sensations.

Results

Sensation of hardness can be qualified mechanically by the stiffness of the material. The indentation curves allow to measure the value of this stiffness K (N/mm) with the following relation:

$$K = \frac{F_{\max}}{\delta_{\max}}$$

With $F_{\max}$ and $\delta_{\max}$ respectively the maximum force (Newton) and depth (millimeter) reached during the indentation. The indentation tests are realized with a steel flat-ended punch (radius r = 5 mm), an indentation velocity of 200 µm/s and a depth δ = 500 µm. For an imposed penetration, the higher the penetration force in the material, the more important its stiffness is. Table 2 and Figure 4 present respectively the stiffness of the hardness samples and the resulting correlation between the sensorial rating and these stiffness values. The graph shows that the sample Hardness 95 which has the more important hardness sensation presents the higher stiffness as well.

Sample	Stiffness (N/mm)
Dureté 10	0.7
Dureté 30	0.6
Dureté 50	1.5
Dureté 75	4.6
Dureté 90	8.6
Dureté 95	9.8

Table 2: Stiffness values of hardness samples measured with a steel flat-ended probe (r = 5 mm).

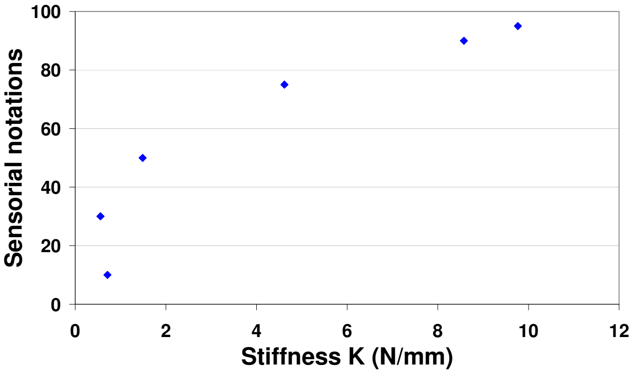


Figure 4: Correlation between sensorial notation and the material stiffness.

Tackiness can be characterized by the parameters of tack force F_{adh}, adhesion energy ω_{adh} and tack distance Δ_{adh}. These adhesive properties have been obtained with an aluminium flat-ended punch (radius r =10 mm). Such probe allows a better approach of the adhesion because of a higher contact between punch and sample. Moreover the area of contact S remains constant during the indentation and is given by the geometry of the probe. For a cylindrical flat-ended indenter $S = \pi * r^2$ where r is the punch radius. The experimental parameters are: the imposed force F_{imp} = 100 mN, the load and unload velocities $v_{ind} = v_{rem}$ = 5 µm/s, the contact time T_c = 0 s. The probe contact surface is cleaned before each indentation in order to eliminate possible residues. For each sample, the resulting tackiness parameters values are presented in Table 3.

	Samples	F_{arr} (mN)	ω_{adh} (µJ/mm^2)	Δ_{adh} (µm)
A	RTV 3428	98	0.012	57
B	Sylgard 184	73	0.008	56
C	RTV 4411	156	0.037	114
D	RTV 4528	335	0.177	254
E	RTV 4408	325	0.143	213
F	RTV 4511	380	0.295	370

Table 3: Adhesion parameters of tackiness samples for an indentation with an aluminium cylindrical flat-ended punch and specific experimental conditions.

Figure 5 illustrates the different correlations between the sensorial notation and the three adhesion parameters. The samples hierarchical organization is the same whatever the mechanical parameter of correlation, except for the samples A and B. Thus sample F which is the stickier material for the experts presents the higher tackiness parameters.

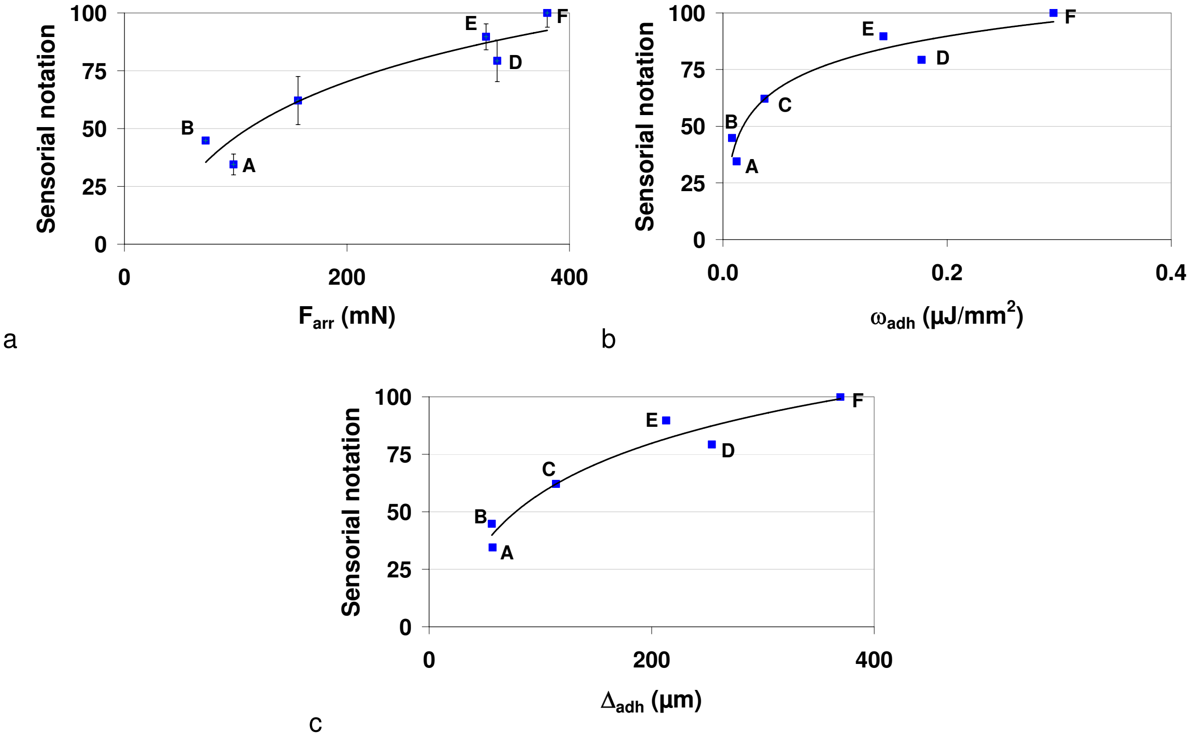


Figure 5: Correlation between sensorial notation and the different adhesion parameters (a: tack force F_{arr}, b: adhesion energy ω_{adh}, c: tack distance Δ_{adh}).

Discussion

The graphs of Figure 4 and Figure 5 show that a correlation between sensorial notation of hardness and tackiness sensations and different mechanical characteristics can be established. Moreover these evolutions seem to follow a logarithmic law as the Fechner's theory plans. According to this theory, sensation intensity evolves with the logarithm of the sensation.

The graph of Figure 4 shows that the hardness sensation can be related to the material stiffness. A logarithmic change of the scale shows a linear evolution between the sensation and the stiffness, except for the sample Hardness 10 which doesn't seem to follow the tendency (Figure 6). Hardness samples are elastomer-like foams and present an air-trapped cells structure. From the sample Hardness 95 to the sample Hardness 10, the cells are becoming larger, yet the measured stiffness can be influenced by the number of solicited cells. For low indentations, the stiffness can be influenced by these cells, which can decrease the material hardness. To avoid this influence, a solution can be to increase the contact surface and the depth of penetration. Another solution would be to realize compact samples with the same material but with different stiffnesses.

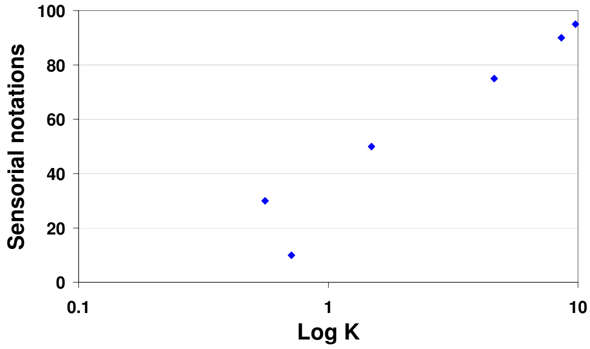
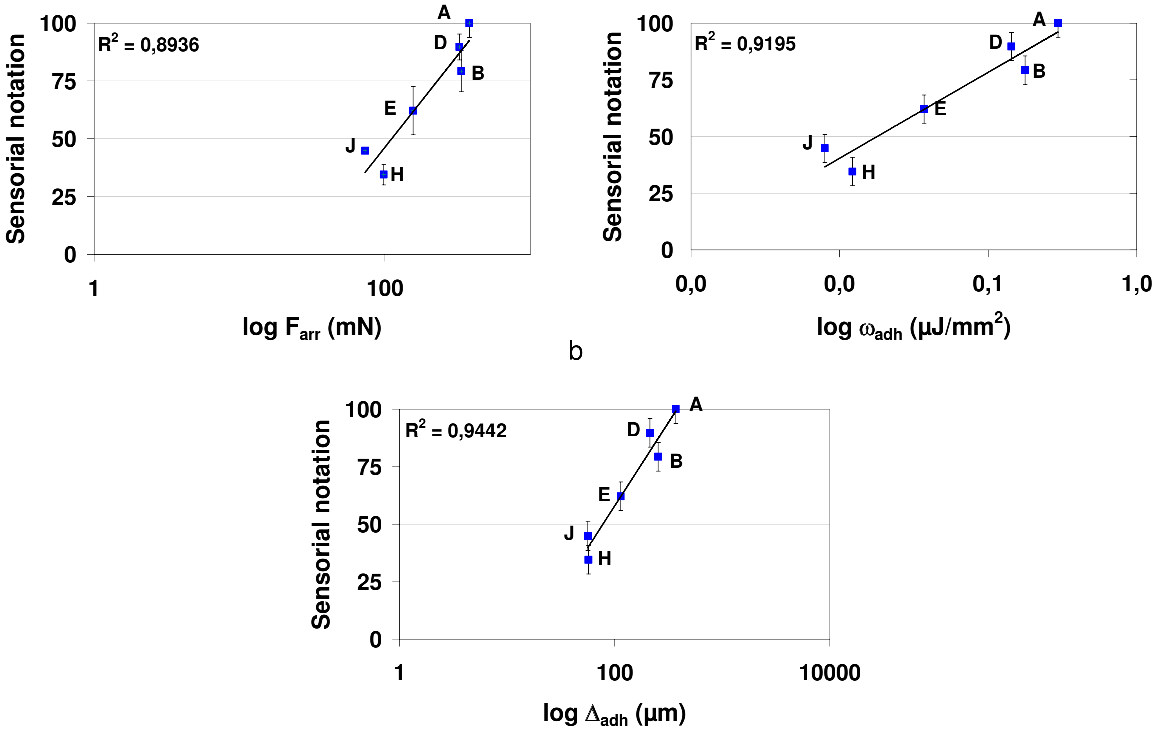


Figure 6: Correlation between the sensorial notation and the samples stiffness on a linear scale.

The different graphs of Figure 5 show that tackiness sensation can be related to the three parameters of adhesion. Like for hardness sensation a logarithm scale curve also shows a linear evolution of the sensorial notation versus tackiness parameters. At the opposite to a first thought tack force F_{arr} is not the best mechanical parameter to characterize tackiness sensation. It seems that the correlation is much better with the tack distance Δ_{adh} (Figure 7). The value of the coefficient of correlation is higher for the correlation with the tack distance than with the tack force ($R^2 = 0.94$ with Δ_{adh} and $R^2 = 0.89$ for F_{arr}). In other words it seems that tackiness sensation is more related to the distance to separate finger from the sample than to the fingerprint force.



a

b

c

Figure 7: Correlation between the sensorial notation and tackiness parameters on a linear scale (a: tack force F_{arr}, b: adhesion energy ω_{adh}, c: tack distance Δ_{adh}).

The different values of adhesion parameters are obtained with specific conditions.

Different authors showed that tackiness can be influenced by the experimental conditions[8-11]. In our study, we have realized different experiments in order to determine the importance of each experimental parameter on tackiness. These experiments showed that the punch diameter, the imposed force or the unload velocity have a great influence on the adhesion phenomenon[12]. In a sensorial test, these experimental parameters represent respectively the finger's size, the applied force on the sample and the velocity to remove the finger from the sample. Though a protocol allows to realize a tactile test with the same finger movement, some parameters are not controllable, because they depend on each individual, in particular the three named parameters above.

Conclusion

Hardness and tackiness sensations can be approached and qualified by the sense of touch. The tested hardness and tackiness samples have been qualified by a panel of experts. The developed probe tack test device allows to qualify and to quantify the properties of hardness and tackiness of materials. Correlations between the sensorial perceptions and the mechanical parameters have been established. The different correlations showed that the hardness sensation can be related to the sample stiffness and the tackiness perception is related to the adhesion energy or the tack distance.

Tack is often associated to a low stiffness: tackiness feeling can be related to the finger's penetration feeling in the sample. For the tackiness samples, it seems judicious to study the influence of the Young's modulus on the sensorial perception. In order to avoid this influence, it is advisable to develop samples which have the same equivalent stiffness. For example it is possible to realize thin films of silicone deposits on a rigid substrate. In the same way, to study hardness sensation it seems to be preferable to realize sample with identical structure in order to avoid its influence on the hardness perception.

Perspectives

Mechanical approach of the hardness and tackiness is realized with cylindrical flat-ended punch (steel or aluminium probe). In order to reproduce with a better fidelity the tactile perception, a silicone finger-like indenter will be used. This indenter will allow to take into account the real nature of human finger (geometry, form, skin deformation, fingerprints…) and will allow a better qualification of the hardness and tackiness perception. In our study, roughness of the probe contact surface has not been taken into account but some authors showed the influence of roughness in the adhesion[13-14]. In sensorial analysis, the fingerprints can be assimilated to roughness. Moreover in order to reproduce the sensation more precisely, mechanical tests parameters should be close to the sensorial analysis ones (finger velocity, pressure exerted by the finger on the sample…).

In this study, the hardness and tackiness sensations have been approached and studied mechanically with a specific metrological device. In the same way, it is also possible to study qualitatively other touch sensations: roughness, slippery, braking, memory of shape… Therefore specific metrology devices should be developed for these sensation studies and correlations can be realized between perceived sensations and mechanical measurements of these sensations. This mechanical alternative should represent a behavioural security, and a saving of time and money. However, it cannot totally substitute to the multi-sensorial analysis realized by human beings.

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