CUSTOM MOLDED SILICON EARPLUGS: EFFECT OF MATERIAL PROPERTIES ON ACOUSTIC ATTENUATION AND MECHANICAL SKIN CONTACT.

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1. MOTIVATION

Silicone is one of the most commonly material used for custom earplugs. Nevertheless, the influence of its mechanical properties on both sound attenuation and mechanical skin contact (which can be assimilated to a comfort factor) are based on empirical statements. The knowledge of silicon's properties is frequently limited to its Shore hardness value which is necessary but insufficient to fully describe the vibro-acoustic behavior of this material. This knowledge can be relevant to improve the design of passive hearing protectors. Viallet et al. [1] performed sensitivity analyses for simulated the acoustic attenuation of a custom earplug however the range of variation chosen for the mechanical properties was arbitrary. Past research works defined and included the contact between the earplug and the skin as mechanical impedance [2] however the variation of this mechanical impedance with the material properties has not been studied yet.

The objective of this work is to quantify the impact of the variation of silicon material properties for both the provided acoustic attenuation and mechanical skin contact. Regarding acoustic attenuation, the choice of an indicator is easy and previous author's works [1] can be compared to the results obtained here for the earplug insertion loss variations. For the mechanical skin contact, this research is more exploratory and one novel indicator has been implemented.

Six medical grade silicones ranging from Shore A 15 to 40 were mechanically tested with a quasi- static mechanical analyzer to get material properties that can be used as a realistic range of variation. Then, a validated 2D axisymmetric finite element model of the occluded auditory canal (acoustical test fixture - ATF - configuration) was used to perform sensitivity analyses upon the range of the measured silicon's mechanical properties.

2. METHOD

2.1 Mechanical properties

The earplug's material is considered as a linear viscoelastic material. The parameters of interest are the following: Young's modulus (E), Poisson's ratio (ν), isotropic loss factor (η) and density (ρ). A quasi-static mechanical analyser (Mecanum) was used to measure the elastical properties of the six selected different types of silicones. The method, according to ISO18437-5, is based on the dynamic compression of two samples of different shape factors combined with polynomial relations, and enable the simultaneous characterization of the elastical properties of interest [3]. The extreme values obtained for each material property are reported in table 1.

Table 1: Extreme values measured for silicon material properties

Property	Min	Max
E (Mpa)	0.395	1.39
ν	0.4	0.49
ρ (kg.m^{-3})	881.8	1085.5
η	0.05	0.25

These extreme values are used as a -1 and + 1 input level code for the design experience detailed hereafter.

2.2 Modeling the EP-EC system and selected indicators

A 2D axisymmetric finite element model of a silicon earplug coupled to an artificial auditory canal, as well as an ATF configuration, was implemented. The model was solved using COMSOL Multiphysics and validated experimentally with attenuation measurments (ANSI-ASA 12-42) carried out with a 45CB ATF. More details about the model can be found in [1].

The insertion loss (IL) was selected as an output indicator to reflect the acoustic attenuation, because of its documented definition in ANSI-ASA S12-42 standard. For the mechanical skin contact, the difference of mechanical impedance's modulus at the skin interface with and without the earplug (Z_{mec}) was calculated and chosen as an indicator. An optimizing value is the minimal distance between those two mechanical impedances. It is important to notice that this relation is local and depend upon the exact position along the interface. In a first approximation, three different positions were considered: at the ear canal entrance (P1), at the middle (P2) and the end of the earplug (P3). Based on these two indicators, two multi-variance analyses were then performed using STATGRAPHICS Centurion software (V16.1.11). The results of these analyses provide the 1st and 2nd order effects of each parameter, i.e. the variation in dB around the average value of the IL or Z_{mec} when the parameter goes from the -1 level to the +1 level codes.

3. RESULTS

3.1 Acoustic attenuation

Figure 1 illustrates the simulated IL together with the first order effects of the material's properties. The top chart shows the possible variation of the IL as a function of frequencies. The bottom part of the figure shows which parameters are responsible for the IL variations. Some classical mechanical effects were retrieved like the fact that the system is driven mostly by it stiffness at low frequencies. An increase of the Young's modulus typically increases the IL up to the first mode of the earplug (around 1 kHz). At higher frequencies all the parameters seem have a comparable influence on IL's variations and some coupling between parameters begins to occur (not shown here for concision).

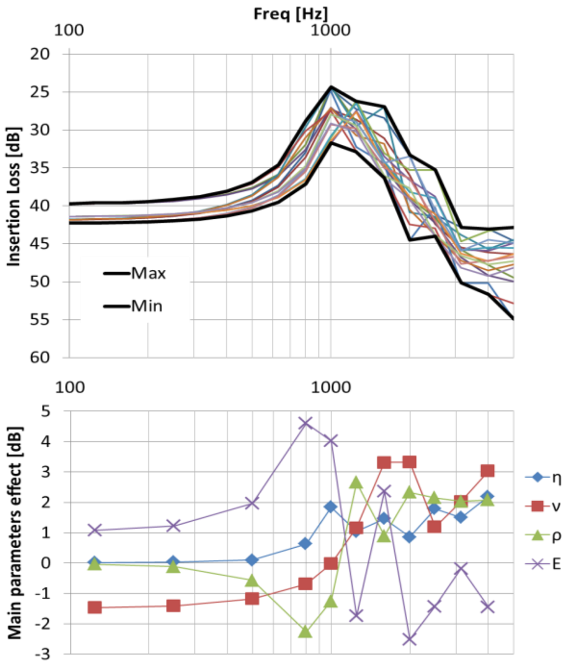

Figure 1: Insertion loss in third octave bands computed for each combination of parameters (16 runs) (top) and the associated first order effects of the material's properties (bottom).

This chart also demonstrates the difficulty to find a unique and/or optimized solution when material properties have negative or positive influences depending on the frequency of interest. These results show that generally the influence for the IL, in dB, is not critical or tremendous (5dB maximum). This founding can be relevant if another indicator has to be optimized, as a function of the material's properties, but without significantly changing the acoustic attenuation.

3.2 Mechanical skin contact

Figure 2 illustrates the simulated variations of the indicator Z_{mec} at the position P2 together with the associated first order effects of the material properties. As well as the acoustic attenuation simulation, the system behaviors become more complex after 1 kHz. At lower frequencies the earplug has a "piston like" behavior and the curves present regular fluctuations. By contrast with the IL results, the main effects are important relatively to the indicator order of magnitude. Up to 1 kHz a decrease of the Young's modulus from level -1 to +1 can reduce by 50% the mechanical impedance difference with and without the earplug. The sensitivity of the indicator Z_{mec} as a function of the position (P1, P2 et P3) exhibits minor differences. An explanation for this minor influence of the position might be the cylindrical geometry (ATF configuration) considered in this work and needs further investigations.

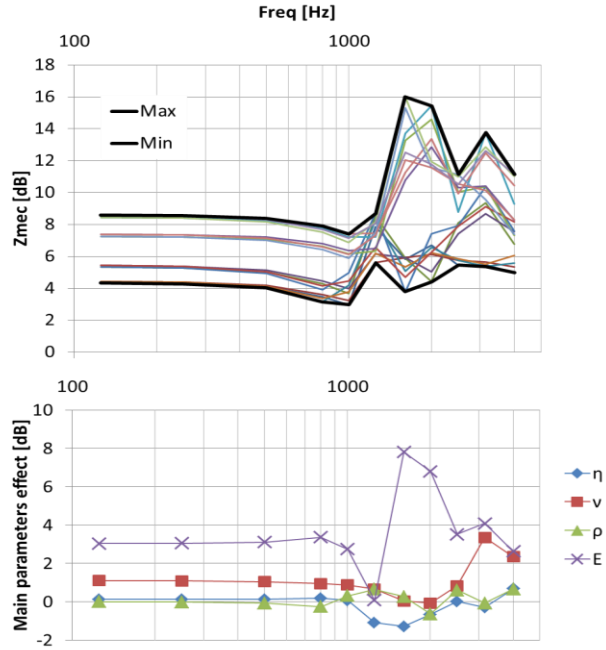

Figure 2: Z_{mec} at position P2 in third octave bands obtained for each combination of parameters (16 runs) (top) and the associated first order effects of the material's properties (bottom).

CONCLUSIONS

In this work, two sensitivity analises relatives to the impact of the material properties of silicone on acoustic attenuation and mechanical skin contact have been presented. Futur works will focus on finding an optimized set of parameters to meet a compromised criteri between effiency and confort for the earplug. The following limitations might be considered for future works. First, the variation of Z_{mec} and its associated sensitivity as a function of the position along the ear canal in a more realistic auditory canal geometry. Second, an adjustement of the range of material properties as a function of the compression rate and the frequency.

REFERENCES

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