2E2-2

Mechanical properties estimation of PVDF polymer using scanning acoustic microscopy

Amit Shelke[1], Shivam Ojha[1], Biswajoy Ghosh[2†], Md. Mamun Molla[3], Frank Melandsø[2], Azeem Ahmad[2], and Anowarul Habib[2*]
([1]Dept of Civil Eng., Indian Institute of Technology Guwahati, India; [2]Dept. of Physics and Technology, UiT The Arctic University of Norway, Norway; [3]Dept. of Mathematics & Physics, North South University, Dhaka, Bangladesh)

1. Introduction

Piezoelectricity is the ability of certain crystalline materials to generate an electric charge in response to applied mechanical stress. Common piezoelectric materials include ceramics like PZT[1)], ZnO, $BaTiO_3$, and $Na/KNbO_3$. While these materials have disadvantages like brittleness, toxicity, non-biodegradability or non-biocompatibility, and complex fabrication processes, polymers stand out for their benefits. Polymers such as PVDF, its copolymers P(VDF-HFP) and P(VDF-TrFE), and poly(vinyl acetate) (PVAc) are also piezoelectric materials used in sensor fabrication[2, 3)]. Polymers are tough, non-toxic, and biocompatible, making them ideal for applications that involve high levels of bending and twisting, as well as for use in biomedical devices[2, 4)]. Piezoelectric polymers are classified into amorphous, crystalline, or semicrystalline types. Among them, polyvinylidene fluoride (PVDF) is a widely used semicrystalline piezoelectric polymer known for its exceptional mechanical, chemical, and thermal stability, as well as its excellent piezoelectric properties. Notably, PVDF is polymorphic, existing in five crystalline phases: α, β, γ, δ, and ε. As previously mentioned, PVDF has a piezoelectrically active component that can be formed into various shapes, including nanostructures, wires, fibers, ribbons, tubes, acoustic sensors, and more[5-7)].

In SAM, high-frequency acoustic transducers made from ceramic, single crystal, or thin films of piezoelectric materials are mounted on a buffer rod and use a concave spherical sapphire lens to focus acoustic energy through water onto the sample plane.

----

email: †biswajoy.ghosh@uit.no, *anowarul.habib@uit.no

The significant impedance mismatch between water and sapphire causes reduced sound transmissivity, bandwidth reduction, and geometrical aberration. To overcome these issues, Smolorz and Grill demonstrated an alternative transducer fabrication method using a flexible PVDF piezoelectric polymer film attached to a spherical epoxy surface [6)]. However, before using PVDF and its copolymer in acoustic transducers, it is important to understand its mechanical properties. Despite its common use in piezoelectric applications, the specific mechanical characteristics of PVDF are not well-documented. To the best of our knowledge, there is no detailed information available in the literature about the mechanical properties of PVDF. Understanding these properties is crucial for optimizing the use of PVDF in acoustic transducers.

2. Sample preparation and experimental setup

In order to prepare the samples, a 2 wt% agarose solution was first created by dissolving agarose in distilled water at 100°C with the help of a magnetic stirrer[8)]. This solution was then poured

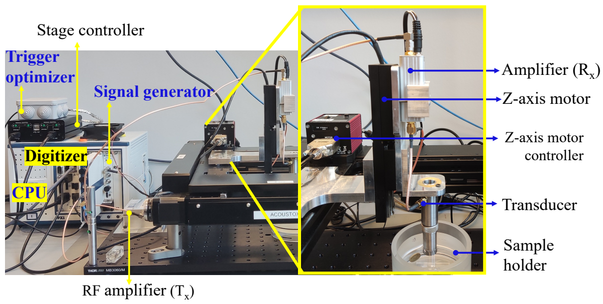

Fig. 1: The figure illustrates the SAM experimental setup for PVDF and target sample imaging[9)].

into a standard Petri dish (μ-Dish 35 mm from ibidi) to form a thick gel layer. Once the gel layer was set, the PVDF sample and the control sample, Polyimide (PI), were carefully pressed into the gel matrix, embedding them securely. We designed a custom-built SAM setup, as shown in Fig. 1, to image the samples [10]. This system featured a Standa high-precision scanning stage (8MTF-200-Motorized XY Microscope Stage) for experimental data collection. Acoustic imaging capabilities were enabled by National Instruments' PXIe FPGA modules and FlexRIO hardware housed in a PXIe chassis (PXIe-1082). Additionally, the setup included an integrated arbitrary waveform generator (AT-1212). The entire system was operated using LabVIEW software. For the imaging process, the transducer was excited with predefined Mexican hat signals. Reflected signals from the samples were then amplified using an RF amplifier. These acoustic reflections were subsequently amplified and digitized at a high speed of 1.6 GS/s using a 12-bit digitizer (NI-5772).

3. Results and discussions

The current study employs maximal overlap discrete wavelet transform (MODWT) and the theory of acoustic to evaluate acoustic impedance and measure the acoustic longitudinal and transversal velocities by observing time delayed in front and back reflections. Both methods are based on the fundamental principles of acoustic wave behavior as applied in SAM. The results obtained through these techniques are illustrated in Fig. 2. and Fig. 3.

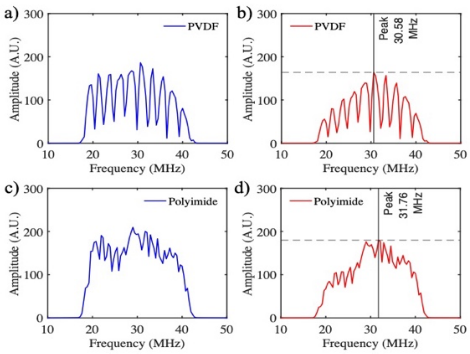

Fig. 2: Displayed in the figures are the frequency spectra of the true responses (a) and (c), as well as the wavelet-transformed signals (b) and (d). These representations provide the identification of primary frequencies.

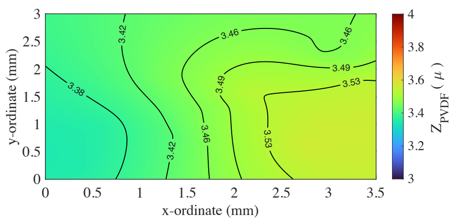

Fig. 3: The figure illustrates the mean value of the specific acoustic impedance of PVDF obtained.

MODWT, Fig.2. demonstrate the filtered response obtained for PVDF and reference material Polyimide in the frequency domain. The characteristic frequency is further used to evaluate the impedance map as shown in Fig. 3. Through proper time mapping of front and back reflection, the longitudinal and shear velocities are obtained as 2385 m/s and 1482 m/s respectively. Next, the mechanical properties of PVDF are summarized in Table 1. Lastly, the mechanical properties of PVDF can be influenced by variations in their composition[11].

Table. 1: Material properties obtained for the PVDF

Description	Mean	Units
Impedance (Z)	3.36	Mrayl
Longitudinal velocity (v_l)	2385	m/s
Shear velocity (v_s)	1482	m/s
Density (ρ)	1.408	g/cm^3
Stiffness modulus (c_{11})	8.013	GPa
Shear Modulus (c_{44})	3.092	GPa
Bulk Modulus (B)	3.890	GPa
Young's Modulus (E)	7.333	GPa
Poisson's ratio (σ)	0.185	-

4. Conclusion

PVDF is a promising material for flexible, transparent transducers used in acoustic imaging. SAM measurements reveal its impedance, longitudinal, and transverse/shear velocities. Finally, these properties were used to calculate Young's modulus, stiffness, shear modulus, and bulk modulus which characterize the PVDF material

Acknowledgment

A. A. acknowledges FRIPRO Young (project # 345136) funding from Research Council of Norway.

References

1) A. Ansari, M.M. Mohebi, S. Baghshahi and R. Tabarzadi: J. Mater. Sci.: Mater. Electron. **29** (2018)17948.
2) P. Saxena and P. Shukla: Adv. Compos. Hybrid Mater. **4** (2021)8.
3) A. Habib, S. Wagle, A. Decharat and F. Melandsø: Smart Mater. Struct. **29** [4](2020)045026.
4) S. Wagle, A. Decharat, A. Habib, B.S. Ahluwalia and F. Melandsø: Jpn. J. Appl. Phys. **55** [7S1](2016)07KE11.
5) J. Xu, M.J. Dapino, D.G. Perez and D. Hansford: Indust. and Comm. App. of Smart Struct. Tech., 2009, p. 58.
6) S. Smolorz and W. Grill: Res. Nondestr. Eval. **7** [4](1996)195.
7) F. Melandsø, S. Wagle, A. Decharat, A. Habib and B.S. Ahluwalia: Jpn. J. Appl. Phys. **55** [7S1](2016)07KB07.
8) S. Ojha, K. Agarwal, A. Shelke and A. Habib: Appl. Acoust. **221** (2024)109981.
9) S.K. Gupta, A. Habib, P. Kumar, F. Melandsø and A. Ahmad: J. Microsc. **292** [2](2023)90.
10) S.K. Gupta, R. Pal, A. Ahmad, F. Melandsø and A. Habib: Sci. Rep. **13** [1](2023)13212.
11) K. Omote and H. Ohigashi: Appl. Phys. Lett. **66** [17](1995)2215.