Variation of acoustic impedance of metals in solid form with ultrasonic velocity

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Abstract

The acoustic impedance is an important characteristic of materials for nearly all sonic and ultrasonic applications. As in the electrical analogy it will determine the efficiency of every transmission in the system from one element to another. The acoustic impedance of an instrument for any particular fingering is one of the major factors which determines the acoustic response of the instrument in that fingering. It determines which notes can be played with that fingering, how stable they are and it also helps determine whether they are in tune. The acoustic impedance also has a large influence on the sound produced.

Key words: Ultrasonic velocity, Acoustic Impedance, Metals in solid form

Introduction

Ultrasonic Waves in Media

It is known that frequency range of sound audible to humans is approxi- mately 20 to 20,000 Hz (cycles per second). Ultrasound is simply sound that are above the frequency range of human hearing. When a disturbance occurs at a portion in an elastic medium, it propagates through the medium in a finite time as a mechanical sound wave by the vibrations of molecules, atoms or any particles present. Such mechanical waves are also called elastic waves. Ultrasound waves or ultrasonic waves are the terms used to describe elastic waves with frequency greater than 20,000 Hz and normally exist in solids, liquids, and gases.The energy of the wave is also carried with it. In a continuous medium, the behaviour of ultrasonic waves is closely related to a balance between the forces of inertia and of elastic deformation. An ultrasonic wave moves at a velocity that is determined by the material properties and shape of the medium, and occasion- ally the frequency. The ultrasonic wave imparts motion to the material when it propagates. This is referred to as particle motion, to distinguish it from the wave motion. This particle motion is usually specified as a parti- cle velocity v. It is noted in ultrasonic measurements that the particle ve- locity is much smaller than wave velocity. Also, one can understand that no ultrasonic wave propagates in vacua because there are no particles that can vibrate in vacuum. The balance between inertia and elasticity develops into a linear relationship between stress σ and particle velocity v, $\sigma = zv$. The proportional factor z is called the specific acoustic impedance of an ultrasonic wave

$z = \sigma/v = \rho c$ where, ρ is the density, and c is the wave velocity. The acoustic impedance characterizes the ability of a material to vibrate under an applied force and can be considered as the resistance of the material to the passage of ultra- sonic waves. There is an analogy between impedance in electrical circuits and the acoustic impedance. The acoustic impedance is useful for treating the transmission of ultrasonic waves between two media, just like that the electrical impedance is effective to characterize a resistance in an alternat- ing electric current circuit. For example, the transmission of an ultrasonic wave from one medium to another becomes maximum when the acoustic impedances of the two media are equal. The concept of using the acoustic impedance plays an important role in determining of acoustic transmission and reflection at a boundary of two media having different material proper- ties and therefore, the acoustic impedance is an important parameter in designing ultrasonic sensors and sensing systems. Ultrasonic velocity is probably the most important and widely used pa- rameter in ultrasonic sensing applications. Each medium has its own value of the velocity that usually depends on not only propagation medium but also its geometrical shape and structure. The theoretical values can be ob- tained from wave equations and typically determined by the elastic proper- ties and density of the medium. Although the velocities can be determined theoretically if material properties such as the elastic moduli and density are known precisely, these material properties are not always available for the determination because they change depending on mechanical processing and heat treatments. Therefore, it is important and necessary to make a calibration measurement for the velocities when one wants to know the correct values for velocities.

The exact fraction of the incident sound which is transmitted or reflected depends on how different the two materials on each side of the boundary are. This is described by the acoustic impedance of the materials, which is related to the density of the material and the speed of sound in the material. The greater the difference in impedance, the more sound will be reflected rather than transmitted. Some typical impedances are shown in the table below:

Medium	Impedance (in standard unit)
air	0.000429
water	1.50
blood	1.59
fat	1.38
muscle	1.70
bone	6.50

Air and water have very different impedances, so that a beam of ultrasound hitting a water surface is almost entirely reflected away, and only a small amount enters the water. The same applies to a beam trying to enter the eye from air.

Acoustic Properties for Metals in Solid Form

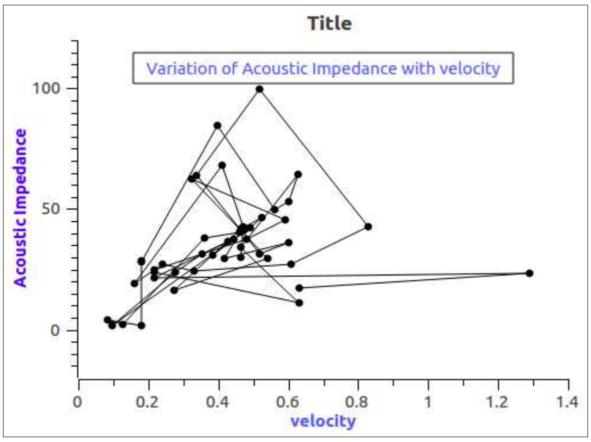
Metals	**Longitudinal Velocity**		**Density g/cm^3**	**Acoustic Impedance g/cm^2-sec x10^5**
	cm/µs	**in/µs**		
Aluminium	0.632	0.2488	2.70	17.10
Beryllium	1.29	0.5079	1.82	23.50
Bismuth	0.218	0.0858	9.80	21.40
Brass	0.428	0.1685	8.56	36.70
Brass, Half Hard	0.383	0.1508	8.10	31.02
Brass, Naval	0.443	0.1744	8.42	37.3
Bronze, Phospho	0.353	0.139	8.86	31.28
Cadmium	0.278	0.1094	8.64	24.02
Cesium (28.5^{o}C)	0.0967	0.0381	1.88	1.82

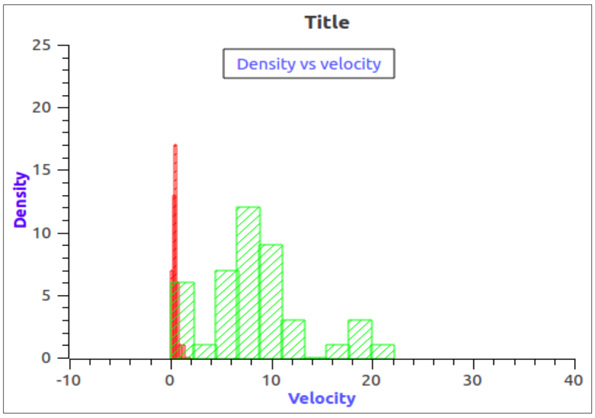
Columbium	0.492	0.1937	8.57	42.16
Constantan	0.524	0.2063	8.88	46.53
Copper	0.466	0.1835	8.93	41.61
Gallium	0.274	0.1079	5.95	16.3
Germanium	0.541	0.213	5.47	29.59
Gold	0.324	0.1276	19.32	62.6
Iron, Cast	0.480	0.189	7.80	37.44
Lead	0.216	0.085	11.4	24.62
Lead 5% Antinomy	0.217	0.0854	1.9	23.65
Magnesium	0.631	0.2484	1.74	10.98
Manganese	0.466	0.1835	7.39	34.44
Molybdenum	0.629	0.2476	10.2	64.16
Monel	0.602	0.237	8.83	53.16
Nickel	0.563	0.2217	8.88	49.99
Platinum	0.396	0.1559	21.4	84.74
Plutonium	0.179	0.0705	*N/A*	28.2
Plutonium (1% Gallium)	0.182	0.0717	*N/A*	28.6

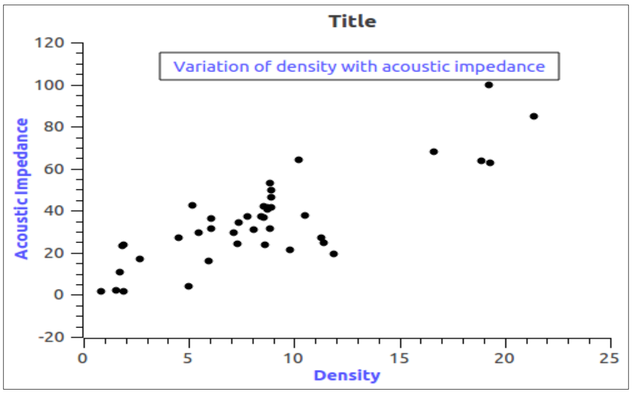
Potassium (100^{o}C)	0.182	0.0717	0.83	1.51
Radium	0.0822	0.0324	5.0	4.11
Rubidium	0.126	0.0496	1.53	1.93
Silver	0.360	0.1417	10.5	37.8
Silver, Nickel	0.462	0.1819	8.75	40.43
Tantalum	0.410	0.1614	16.6	68.06
Thallium (302^{o}C)	0.162	0.0638	11.9	19.28
Thorium	0.240	0.0945	11.3	27.12
Tin	0.332	0.1307	7.29	24.2
Titanium	0.607	0.239	4.50	27.32
Titanium Carbide	0.827	0.3256	5.15	42.59
Tungsten	0.518	0.2039	19.25	99.72
Uranium	0.338	0.1331	18.9	63.88
Uranium Dioxide	0.518	0.2039	6.03	31.24
Vanadium	0.600	0.2362	6.03	36.18
Zinc	0.417	0.1642	7.10	29.61
Zircaloy	0.472	0.1858	9.03	42.6

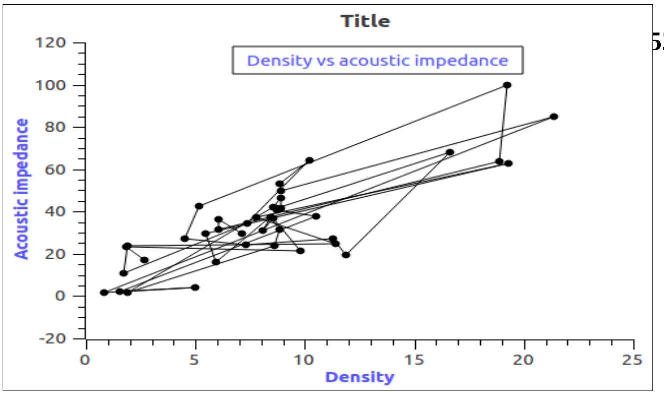
Zirconium	0.465	0.1831	6.48	30.1

Table.2 Data compiled by Xactex Corporation









Results and Discussion

The velocity of sound in a material depends on the elastic constants and density of those materials. Thus, direct measurements of velocity determine the elastic constants provided that the density can be evaluated by another method, e.g. by measuring the volume and weighing or by using a hygrometer. Both the elastic constant and the density vary with temperature, concentration, nature of alloy, structure, and so on, and the measurement of the velocity may yield information about one of these quantities provided that the others remain constant or can be measured independently. Tungsten belongs to the group of refractory metals. Refractory metals are metals that have a higher melting point than platinum (1 772 °C). In refractory metals, the energy binding the individual atoms together is particularly high. Refractory metals have a **high melting point** coupled with a **low vapor pressure**, **high modulus of elasticity** and **good thermal stability**. Refractory metals are also typically characterized by a low **coefficient of thermal expansion** and relatively **high density.**Tungsten has the **highest melting point of all metals** as well as a remarkably high modulus of elasticity. In general, its properties are similar to those of molybdenum. The two metals are located in the same group in the periodic table.

Highest values	Density	Acoustic Impedance
Tungsten	19.25	99.72
Platinum	21.4	84.74
Lowest values		
Potassium (100^{o}C)	0.83	1.51
Cesium (28.5^{o}C)	1.88	1.82

However, some of the properties of tungsten are more pronounced than they are in molybdenum.The material's **high thermal stability** coupled with its **high modulus of elasticity** give tungsten its **high creep resistance**.PLATINUM, a silvery-white metal and the most common and widely used of the platinum group metals (PGMs), is also one of the most precious metals. As with all of the PGMs but especially so in its case, platinum has many unique properties making it ideally suited to advanced technical applications. As one of the densest and heaviest metals known to man, platinum is also extremely durable. It is also very malleable and ductile. Although it has a very high melting point (1,772°C), it is stable at extremely high temperatures. In addition to being resistant to corrosion and chemical attack, it is a very good conductor of electricity, is a powerful catalyzing agent and is recyclable. Platinum is primarily used in the jewellery and automotive industries, with the latter making use of its excellent catalytic properties. Platinum metal has a number of useful properties, which explains its application in a wide-range of industries. It is one of the densest metal elements almost twice as dense as lead and very stable, giving the metal excellent corrosion resistant properties. A good conductor of electricity, platinum is also malleable and ductile.

Conclusion

In this paper a brief overview of fundamentals in ultrasonic sensing is presented by using data for various metals collected by Xactex Corporation. Some advanced techniques and applications to non-destructive evaluation are also introduced. The essentials of ultrasonic sensing are how to drive an ultrasonic wave into an object and how to capture the ultrasonic wave from the object. In addition, another essential is how to extract the information we want from the captured ultrasonic wave. To accomplish these and to create a useful sensing technique, it is indispensable to make an effective collaboration among researchers in different fields of engi- neering and science such as electrical, electronics, information, mechanical and materials.

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