Copper-Clad Aluminum Wire DCCA for Speakers on Mobile Devices

Yui KOIWA*, Mitsuharu SUGAWARA, and Masaaki FUKUHARA

With the spread of mobile devices, market needs are increasing for the improved sound quality of small speakers. Self-bonding magnet wires used in the voice coils of small speakers are required to be durable against vibration and to be lightweight for enhanced responsiveness in a high-frequency range. Our copper-clad aluminum wire is resistant to fatigue fracture caused by vibration. The wire comes with various densities and conductivities by changing the composition ratio of the copper coat and aluminum core. This paper reports on the development of the wire that has increased flexibility in coil design and durability for the improved sound quality of small speakers.

Keywords: CCA, speaker, voice coil

1. Introduction

With the recent spread of mobile devices and consequent increase in opportunities to listen to sound produced by them, not only when communicating on the phone, but also when listening to music or watching videos, there is a growing need for these devices to demonstrate improved sound quality.

For more than 20 years, DAIKOKU ELECTRIC WIRE CO., LTD. has provided various types of self-bonding magnet wires (hereinafter, self-bonding wires) for the application of voice coils,*[1] which are used as acoustic parts. In particular, small-size speakers*[2] called micro-speakers are generally equipped with air-core voice coils, which maintain their shape by the effect of bonding layer on the wires. Self-bonding wires for this application are usually connected directly to terminals without using lead wires, and are therefore frequently subjected to vibratory loads. For this reason, they are required to be resistant to fatigue fracture. Nevertheless, for applications in which improved sound quality is especially required, copper-clad aluminum (CCA) wires have also been adopted as the conductor of self-bonding wires for a long time while sacrificing resistance to fatigue fracture.

In response to such market needs, we attempted to develop conductors that provide compatibility between resistance to fatigue fracture and sound quality. This paper reports on the development of the conductors, which have been released under the product name “DCCA wires.”

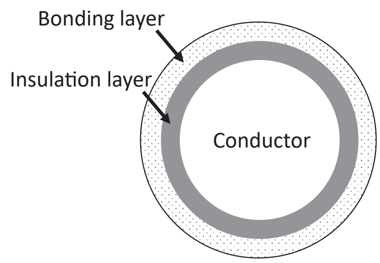


Fig. 1. Cross-section view of self-bonding wire

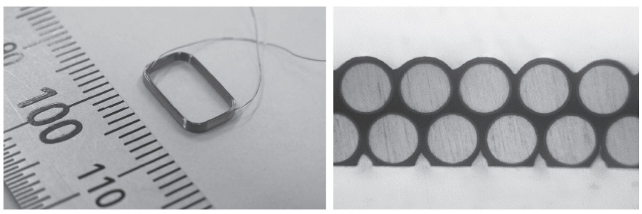


Photo 1. Air-core voice coil and its cross-section

2. Acoustic Parts and Self-bonding Wires

2-1 Acoustic parts of mobile devices

Mobile devices, as typified by smartphones, are equipped with air-core voice coils (Photo 1) made of self-bonding wires (Fig. 1), typically for three parts: speaker, receiver and earphones.

(1) Speaker

With the spread of ringtones for mobile phones and the consequent need for improved sound quality, dynamic speakers*[3] have become standard for mobile devices. Widely used for watching videos as well as listening to music, today’s mobile devices also play the role of portable audio players. Accordingly, improved output power and sound quality are increasingly being required for the speakers of mobile devices.

(2) Receiver

Systems to listen to voice over the telephone line are called receivers. Since receivers are positioned close to the ear, their output power does not need to be as high as that of speakers. With the emergence of mobile devices with stereo audio function, some models are equipped with a receiver that doubles as a speaker.

(3) Earphones

Earphones, which are worn in the ears, produce sound by converting signals received from mobile devices through wired or wireless communication. Since earphones produce sound in the ears, the sense organs of human beings, the required output power is low but improved sound quality has been required for a long time.

2-2 Working principle of acoustic parts

All the above acoustic parts are devices that convert electrical energy into sound via kinetic energy. When a conductor (voice coil) in a magnetic field is energized, a force is produced by the electromagnetic effect. A membrane (diaphragm) stuck to the voice coil is driven by this force, producing a slight air vibration, namely sound (Fig. 2).

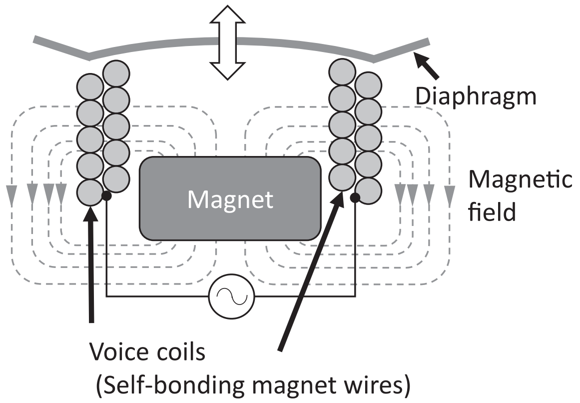


Fig. 2. Schematic view of internal magnet-type dynamic speaker

2-3 Characteristics required for conductors constituting voice coils for micro-speakers

In ordinary speakers, bobbin-wound voice coils made of self-bonding wires are connected to terminals via flexible wires, such as tinsel wires. On the other hand, in micro-speakers, the self-bonding wires that constitute air-core voice coils are usually connected directly to terminals without using lead wires. Therefore, conductors in the self-bonding wires are required to be resistant to fatigue fracture caused by the vibration of the voice coils.

In addition, unlike audio devices equipped with multiple speakers designed for individual output frequency ranges, these acoustic parts for mobile devices are required to be full-range speakers (speakers with full-frequency-range performance). Therefore, designing voice coils that can produce appropriate sound pressure levels (dB) across a wide frequency range (impedance and weight) is important (Fig. 3). For this reason, the designers of micro-speakers have tried various conductors for self-bonding wires. As a result, for applications in which sound quality is especially important, CCA wires, which will be described later, have been preferred for their ability to maintain sound pressure levels up to higher frequency ranges.

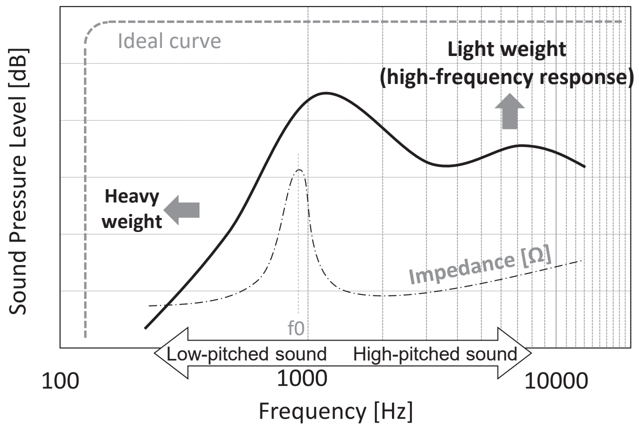


Fig. 3. Concept of frequency and sound pressure level

3. Development of DCCA Wires

3-1 CCA wires

CCA wires have a hybrid structure consisting of an aluminum core and copper clad (Fig. 4). They are manufactured by cladding using copper strips or tubes, or by copper plating, and generally classified and labeled by the volume ratio (%) of copper clad.

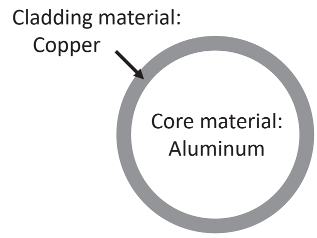


Fig. 4. Cross-section view of CCA wire

In the 1970s, standards for CCA wires were established in the ASTM standards.*[4] For some applications of voice coils, such as earphones, DAIKOKU ELECTRIC WIRE has provided self-bonding wires using ASTM-compliant 10- and 15-vol%-Cu CCA wires as a conductor.

CCA wires are designed based on the concept that the aluminum core provides light weight while the outer clad layer provides the advantages of copper, such as ease of bonding with terminals. Therefore, the advantage in terms of weight reduction is presumed to be the reason why CCA wires with comparatively thin copper clad have been provided.

3-2 Selection of aluminum materials

As described above, aluminum makes up a large part of the volume of CCA wires. Therefore, we attempted to improve resistance to fatigue fracture by altering the conventional aluminum material as a more promising method to improve this property. We proceeded with the selection of materials by mainly evaluating tensile strength, which we regarded as a substitute index for resistance to fatigue fracture, as well as electric conductivity and availability.

3-3 Properties of developed CCA wires

We created 15-vol%-Cu CCA wires using the selected aluminum alloy, and measured the properties of self-bonding wires with a conductor diameter of 0.050 mm. As a result, we confirmed that the tensile strength of developed CCA wires is higher than that of conventional CCA wires by 25% or more, although electric conductivity was lower. We also confirmed that tensile strength becomes even higher than that of copper wires depending on annealing conditions (Table 1).

Table 1. Properties of self-bonding wires made of developed CCA wires with a diameter of 0.050 mm

Conductor			Copper	CCA	Developed CCA	
	Copper clad ratio		(100%)	15%	15%	
	Core material		—	Pure aluminum	Selected aluminum alloy	
Conductor Diameter		[mm]	0.05	0.05	0.05	0.05
Overall Diameter		[mm]	0.065	0.065	0.065	0.065
Tensile Strength		[MPa]	285	199	252	341
Elongation		[%]	20	9	7	3.7
Electric Conductivity		[%(IACS)]	100	66	62	63

3-4 Evaluation of resistance to fatigue fracture

We conducted bending fatigue testing to confirm the improvement in resistance to fatigue fracture (Fig. 5).

In the testing of developed CCA wires with a diameter of 0.080 mm (bare wires), which have the same tensile strength as copper wires, we confirmed significant improvement in the number of times of bending until wire breakage compared to conventional CCA wires and the same level of bending life as copper wires (Fig. 6).

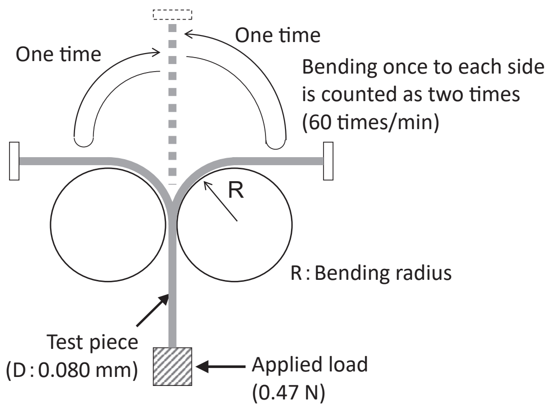


Fig. 5. Schematic view of bending fatigue testing

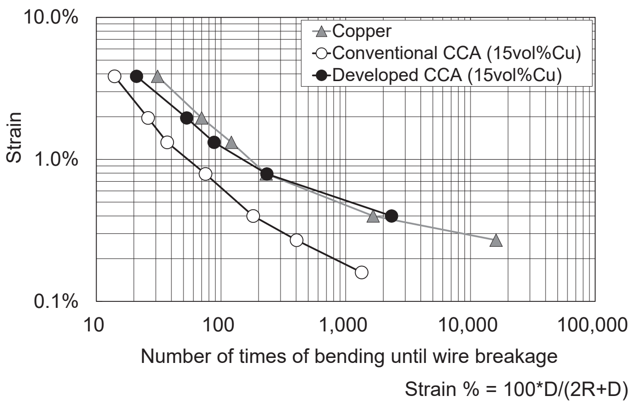


Fig. 6. Evaluation of developed CCA wire's resistance to bending fatigue fracture

3-5 Launch of developed CCA wires

After passing a customer evaluation, in 2010, self-bonding wires using the developed CCA wires as the conductor were launched onto the market. We named the developed CCA wires "DCCA wires," incorporating the initial of our company name to represent that they are our original CCA wires.

4. Expansion of Options for Copper Clad Ratios

4-1 Necessity to expand options for copper clad ratios

Speaker efficiency η is represented by the following formula[(1)]:

$$\eta\ [\%] = 100 \times W_a/W_e = (50\pi\rho a^4 B^2 m_v)/c(m_v+m_d+2m_a)^2 \times (\kappa\rho)^{-1} \quad \cdots\cdots\cdots\cdots\cdots (1)$$

W_e:Electrical input power (W)
W_a: Acoustic output power (W)
B: Air-gap magnetic flux density (G)
a: Effective vibration radius (cm)
m_v: Weight of voice coil (g)
m_d: Weight of diaphragm (g)
m_a: Added mass of diaphragm due to the surrounding air (g)
M_0: Total weight of vibrating system (g) ($M_0 = m_v + m_d + 2m_a$)
κ: Specific resistance of conductor in voice coil (Ω · m)
ρ: Density of conductor in voice coil (g/cm^3)

Formula (1) shows that the weight and electric resistance of voice coils have a significant effect on speakers' output power, namely, sound quality. Unlike bobbin-wound coils, with which M_0 can be adjusted by changing bobbin weight, air-core coils have limited means to adjust sound quality due to fewer conductor options. Therefore, it was presumed that speaker designers optimized sound quality by modifying the design of the entire speaker, mainly parts such as diaphragms and magnets.

Then, looking at variations in physical properties according to the constituent ratio of copper and aluminum, we attempted to expand the options for the weight (m_v) and electric conductivity (κ) of voice coils by providing DCCA wires of a wider range of copper clad ratios.

4-2 Expansion of options for DCCA's copper clad ratios

We gradually increased the options for copper clad ratios while carefully monitoring customer responses by providing samples. As a result, the copper clad ratio lineup has been expanded to 80-vol% (Fig. 7, Photo 2). Currently, in the category of micro-speaker applications, there is a tendency for voice-coils with higher electric conductivity and density to be preferred to those made of 15-vol%-Cu CCA wires, which used to be in common use as the standard type, because the former's lower minimum resonance frequencies*5 lead to expansion of the output frequency range of speakers (Fig. 3). For this reason, an increasing number of customers are considering or currently using mainly 30- to 50-vol%-Cu DCCA wires.

This fact indicates that our development activities have contributed, to no small extent, to providing more flexibility in designing speaker coils as intended.

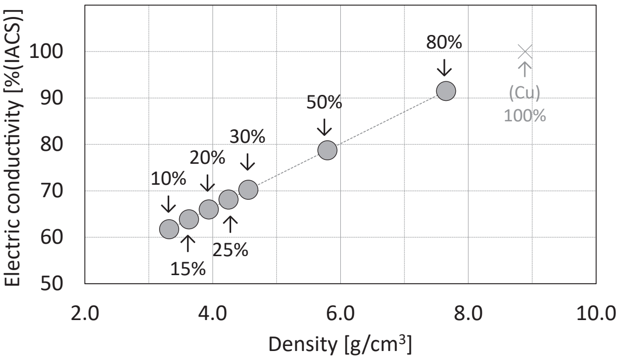
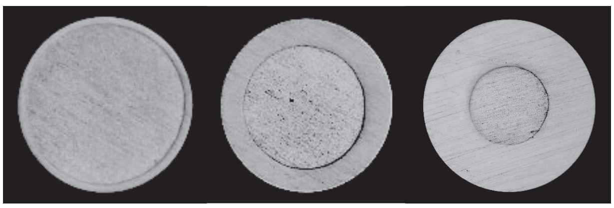


Fig. 7. Density and electric conductivity of DCCA wires



(a) 15%DCCA (b) 50%DCCA (c) 80%DCCA

Photo 2. Cross-section of DCCA wires with different copper clad ratios

5. Conclusion

CCA wires used to be in limited use for some earphone applications. However, since the launch of DCCA wires, use of CCA wires for the acoustic parts of mobile devices, including speakers, has become more common, and their share has been growing in recent years. The number of smartphones delivered in the world reached its peak in 2016, and the market has almost become saturated. However, acoustic technologies for mobile devices are expected to be diverted to other sound-producing applications in our daily lives, such as in-car and AI speakers.

In response to numerous requests for further property improvement, we will continue to make efforts to improve sound quality while taking advantage of our experience over many years and the Sumitomo Electric Group's comprehensive strength.

Technical Terms

∗1 Voice coil: Coils to produce driving force by using the electromagnetic effect. There are bobbin-wound voice coils and air-core (bobbin-less) voice coils.

∗2 Speaker: Generic term for devices that convert electric signals into sound signals

∗3 Dynamic speaker: Also known as "electrodynamic speaker," which produces sound by vibrating a diaphragm with coils driven by the electromagnetic effect

∗4 ASTM standards: International standards established by ASTM International. ASTM-B566[2] (originally approved in 1972) provides standards for 10- and 15-vol%-Cu CCA wires (both are subclassified into A-type and H-type).

∗5 Minimum resonance frequency: The low-range frequency at which impedance reaches a peak (f0 [Hz]), which is regarded as an index of lowest output frequency.

References

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