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Effects of arc during mechanical bounces on contact material for different power supply frequencies

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Abstract

During a make operation in an electromechanical switching device, an electrical arc could occur because of mechanical bounces and can cause serious damages, such as contact welding and electrodes erosion. The characteristics of this arc are influenced by several parameters such as the level of voltage and current, the load of circuit, the nature of contact materials and, a parameter that we will focus on, the voltage frequency.

Indeed, for frequencies equal or greater than 50 Hz, the current can go through zero several times during typical mechanical bounce. The energy transferred to the electrodes, which will condition the welding, depends on the total arc duration, and so on the reignition of the arc.

In order to investigate this phenomenon, the contacts welding in relation with the re-ignition of arc have then been studied for different frequencies. The make tests were done for 115 Vrms/750 Arms with a mechanical bounce of 2 ms, with different frequencies 50 Hz/ 400 Hz/ 500 Hz and with AgSnO₂ contact material and silver contacts as reference. The welding characteristics, such as welding occurrence and force were measured as a function of arc characteristics (voltage/current/energy).

Finally, this investigation showed the importance of the voltage frequency on contactors reliability.

1 Introduction

Switching devices like contactors play an important role in an electrical network. In the area of aeronautics, an ongoing evolution of electrical network is taking place to improve the performance of the vehicles. Therefore, the number of electrical contactors has increased. Consequently, from a statistical point of view, it could cause more deficiencies such as overheating and contact welding.

Welding phenomenon is one of the most important issues which could take place at the contacts closure [1], [2]. It could damage the switch and consequently influence the safety and driveability of the vehicle. Therefore, for a better understanding of this phenomenon, it was the subject of multiple studies [3–8] in which the authors tried to show the influence of different parameters on it such as arc energy, material nature and contact force.

In the present study, contact-welding and their characteristics have been studied in different power supply frequencies, 50 Hz, 400 Hz and 500 Hz, as well as the bounce arc characteristics. AgSnO₂ contacts have been used for this study. They are well known by their anti-welding aspect [2], [8–10]. Pure Silver contacts have been used as a reference.

The electrical current, the contact material nature, the kinematic of the contact, are well known to have significant effect on welding characteristics [1], [2]. By having an effect on arc characteristics, voltage frequency, which influence arc duration may also have an influence on contact welding. The purpose of this work is to

determine how AC current may influence the welding phenomenon.

An approach of the problem indicates that high frequency would lead to short arcs [11] and consequently weak welding. Indeed, a short arc injects less thermal energy on the arc spot, thereby decreasing the amount of molten zone. However, this study showed that this approach is too simplistic.

2 Experimental part

2.1 Welding test bench

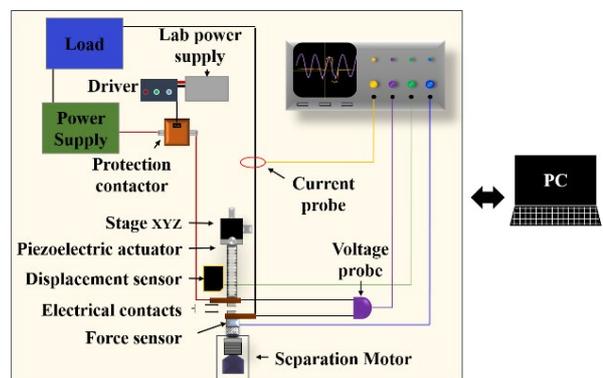


Fig.1 Scheme of the testing equipment for make tests

Based on the model of Morin et al [8], an experimental test bench has been designed to characterize the bounce arc and the contact welding (Figure 1).

In this test bench, a piezoelectric actuator, fixed on the anode, reproduces a controllable mechanical bounce during the electrodes closing, which helps to eliminate nearly the different softness and damping effect of the contact material.

The displacement motor applies a chosen contact force, which is adjusted thanks to the force sensor. This force sensor fixed on the cathode also measures the supplementary force required to separate the contacts in case of sticking, called welding force. The contacts are considered definitely stuck when the welding requires an effort superior to the pulling force of the displacement motor equal to 100 N.

The arc voltage and current are measured by probes. The laser displacement sensor is placed behind the piezoelectric actuator. It allows to check the profile of the bounce. These measuring instruments are connected to an oscilloscope. Figure 2 shows an example of acquired data by the oscilloscope. These data allow to determine the arc duration, the arc energy and the height of the bounce.

All the instrumentations allowing data acquisition (motor, power supply, oscilloscope, voltmeter, displacement sensor, force sensor) are connected by USB bus and controlled by a computer.

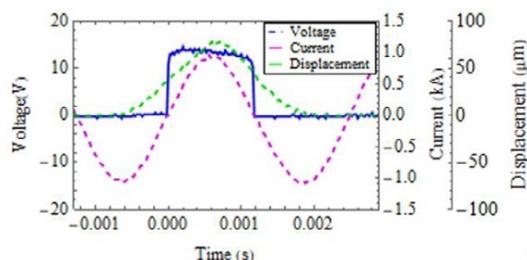


Fig. 2 Voltage and current of a bounce arc and the height of the bounce during a make test.

Table 1 shows the mechanical and electrical conditions of the tests.

Source voltage	115 Vrms
Current	750 Arms
Load type	Resistive
Contact force	6 N
Welding force lower limit	2 N
Atmosphere	Ambient air
Bounce height	80 µm
Bounce duration	2 ms
Number of Bounces	1
Motor pull capacity	100N

Table.1 Tests conditions for bounce arc

2.2 Samples Material

Silver-based contacts are the most frequently used on electrical switching devices. The addition of tin oxide

provides an anti-welding effect, by facilitating the welding fracture.

The samples used for these tests are tips with two types of materials: pure Silver and AgSnO₂ (10 wt.% SnO₂). The electrodes have curved surfaces with a radius of 300 mm. The diameter of those samples is 16 mm.

3 Results and discussion

3.1 Welding force vs voltage frequencies

Table 2 summarizes the results of welding phenomenon obtained from the make tests. It shows the maximum welding force, the welding occurrence rate, and the average welding force of Silver and AgSnO₂ samples for the test frequencies 50 Hz, 400 Hz and 500 Hz.

Frequency [Hz]	Sample Code	Contact Material	F _s max [N]	F _s mean [N]	Welding rate [%]
50	S50	Silver	>100	>100	100
	AS50	AgSnO ₂	76.8	13.5	91.7
400	S400	Silver	80	12.2	81.5
	AS400	AgSnO ₂	68	13.7	90
500	S500	Silver	83	17	90.5
	AS500	AgSnO ₂	78	15.39	92

Table.2 Contact welding characteristics

F_{smax} corresponds to the strongest welding that the separation motor could break. When the contacts are definitely stuck (F_{smax}>100), the number of tests stops.

For the test done with the frequency 50 Hz, the silver sample S50 has been stuck definitively since the first operation. On the other hand, for silver samples S400 and S500 a number of 450 and 240 cycles were carried out respectively.

Concerning AgSnO₂ samples, the definitive sticking has been reached after 400 cycles for AS50, 500 cycles for AS400 and 100 cycles for AS500. This shows that the service lifetime of the contacts is not related linearly to the voltage frequency.

Moreover, except for the case of the sample S50, the average welding forces of S500 and AS500 (500 Hz) are the highest besides the average welding forces of the rest of the samples.

Figure 3 highlights the visualisation of the welding force trending, and the maximum force for each period of Silver and AgSnO₂ contacts tested at different frequencies: 50 Hz, 400 Hz and 500 Hz.

For AgSnO₂ contacts (AS50, AS400 and AS500) the impact of ageing is considerably notable on the welding force, it increases according to the service time. Nevertheless, cases of strong welding over 60 N are exceptionally observed in the beginning of the contacts lifetime. Contrary to the silver contacts (S400 and S500), there is a fluctuation of welding force throughout all their lifetimes.

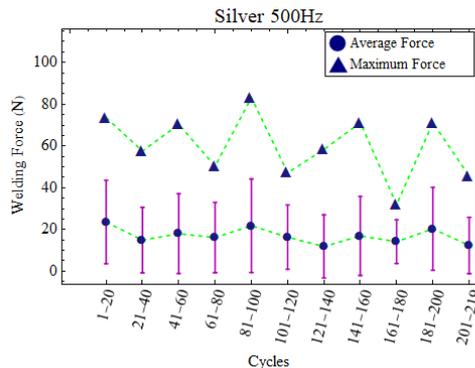
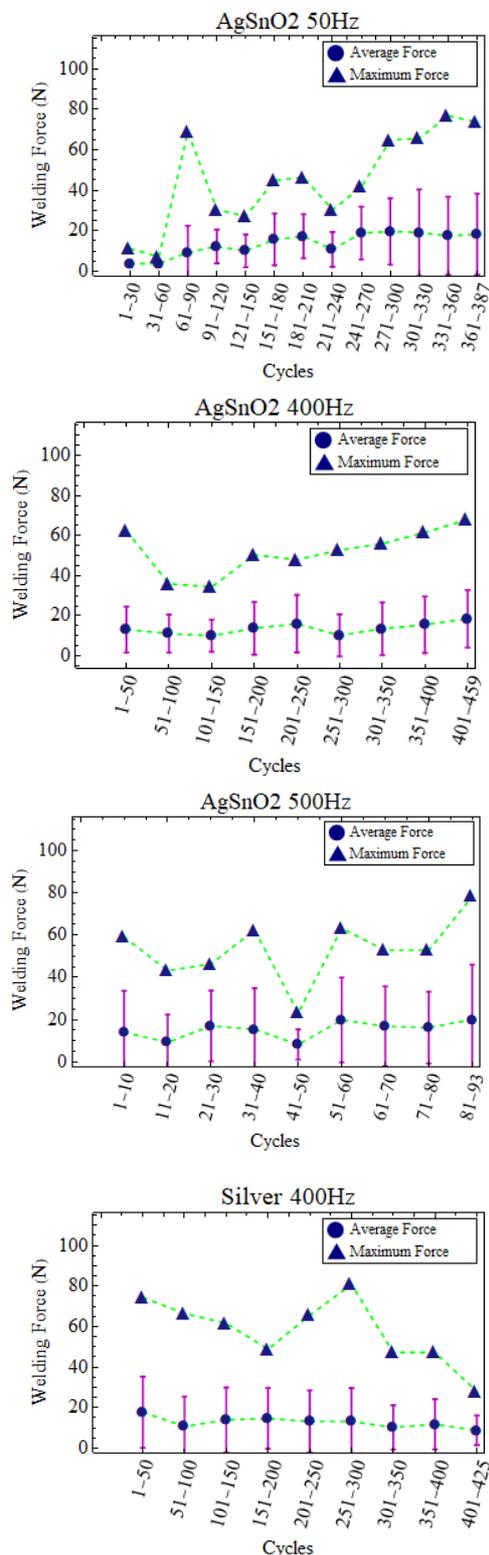
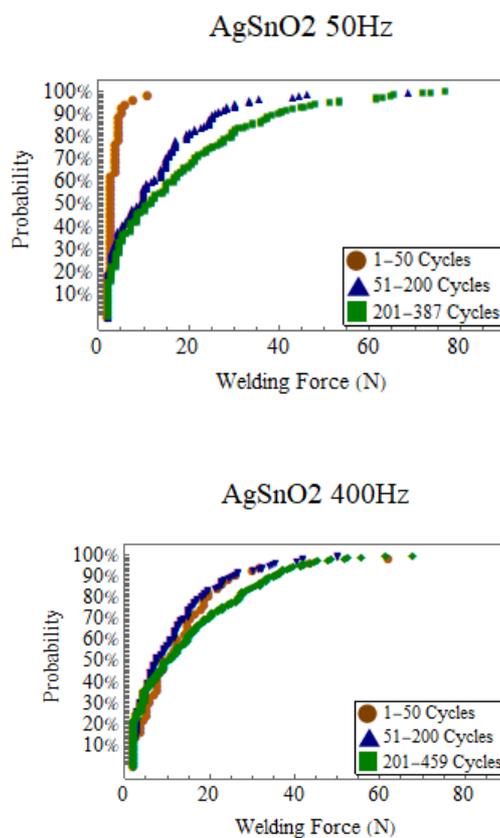


Fig. 3 Welding average force vs. test cycles

Furthermore, Figure 4 presents the cumulative distribution curves of welding force versus different lifetime periods (the beginning, the middle and the end). It shows that despite that contact ageing has a slight impact on the welding force, AgSnO₂ and silver samples have an opposed behaviour with time.

AgSnO₂ sample starts by the occurrence of small welding forces and ends by occurring high ones. In the other hand, it is observed that for the Silver samples during the first periods, the occurrence of high welding force is greater than the rest of the contacts lifetime.



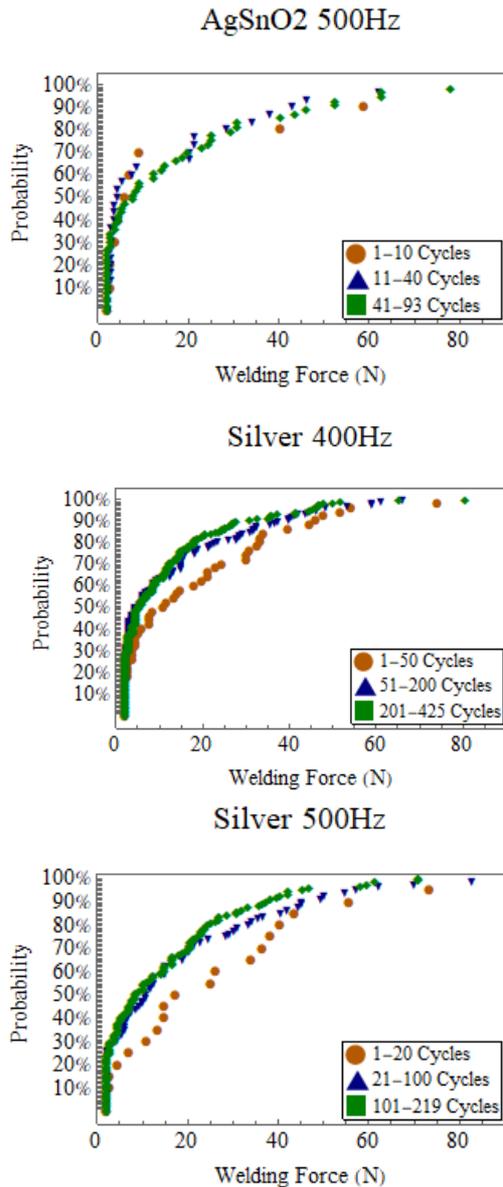


Fig. 4 Cumulative distribution of welding force for different lifetime periods

In order to understand this welding behaviour, the arc characteristics (duration and reignition) and the arc energy are presented in Figure 6-7 and 8 respectively.

3.2 Arc duration vs voltage frequencies

The bounce arc could stay ignited till the definitive contacts close, which means that the arc duration is equal or less than the bounce duration. Nonetheless, the definitive arc extinction could be conditioned by the voltage frequency.

In the literature, the arc ignition requests a power supply voltage greater than 12 volts and a current above 400 mA for Silver [2], [11]. Hence, the maximal arc duration is depending on the frequency. Therefore, under this approach, the arc duration could not be higher than the half-period of the voltage waveform. Figure 5 below

shows the maximum arc duration that could have occurred following this approach.

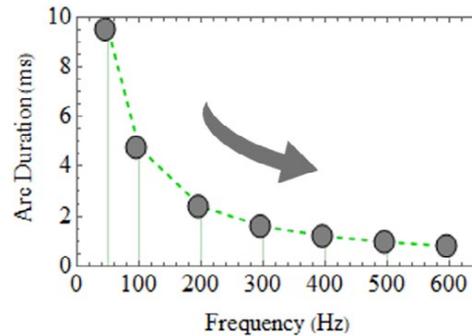
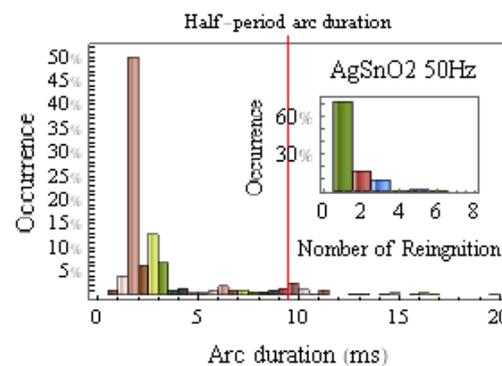


Fig. 5 Arc durations during a voltage half-period waveform vs. voltage frequency for 115 Vrms

Nevertheless, at all the tested frequencies, 50 Hz, 400 Hz and 500 Hz, the arc durations were measured and part of them exceeded the half-period duration of the voltage waveform of each frequency as shown in Figure 6. The occurrence of reignition is showed also in the same figure. As observed in these figures, the reignition number increases by increasing the voltage frequency. This explains the observed long arc durations for AS400 and AS500. This phenomenon takes place for the majority of tests. It could depend not only on the frequency of the current but also on the nature of contact materials and the condition of contact surface. Actually, the arc reignition may happen because of a residual plasma existing in the contact gap [12], this reignition causes a splashing of melted metal, which helps to increase the melted surface and consequently increase the welding occurrence. Figure 7 shows two examples of arc reignition for 50Hz and 500Hz and an example where the arc extinguishes after the first ignition.

Beyond the phenomenon of reignition, towards the end of tests, the contacts became very rough. This leads sometimes to a mechanical perturbation, which leads to create small bounces after the main applied one.



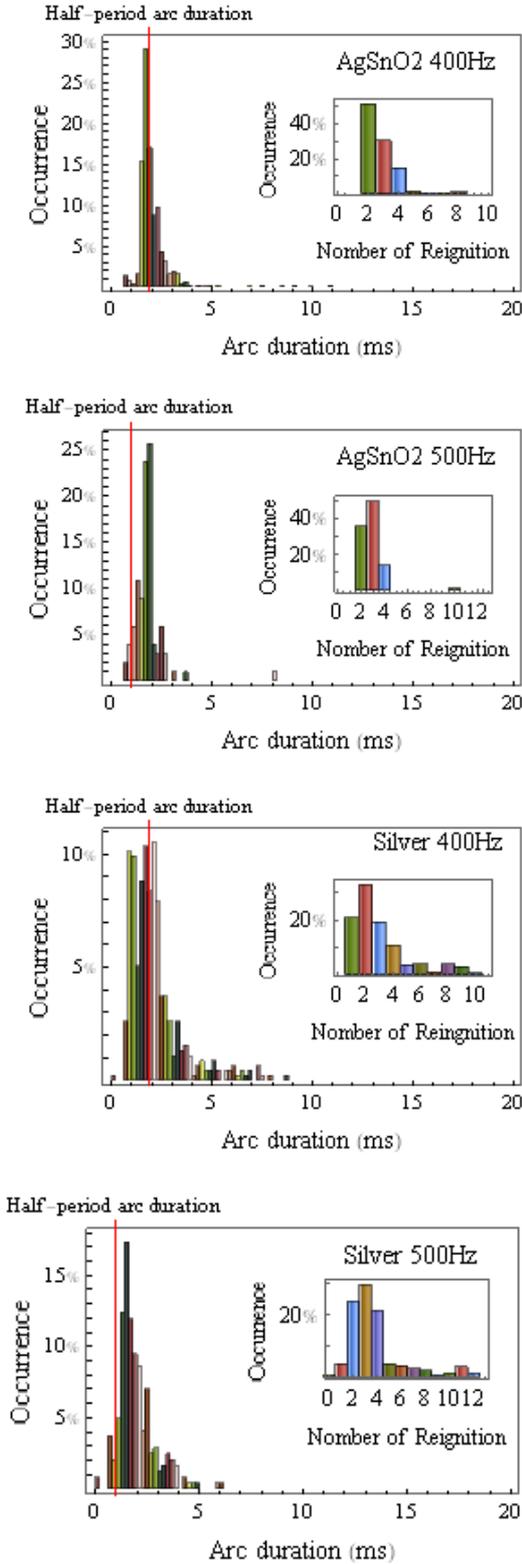


Fig. 6 Bounce arc duration occurrence vs. voltage frequency

The longer arc duration may also be caused by evaporated and molten contact material, this could be influenced by several factors such as the material structure and the pressure, but it is still a complex phenomenon requesting a precise investigation and understanding.

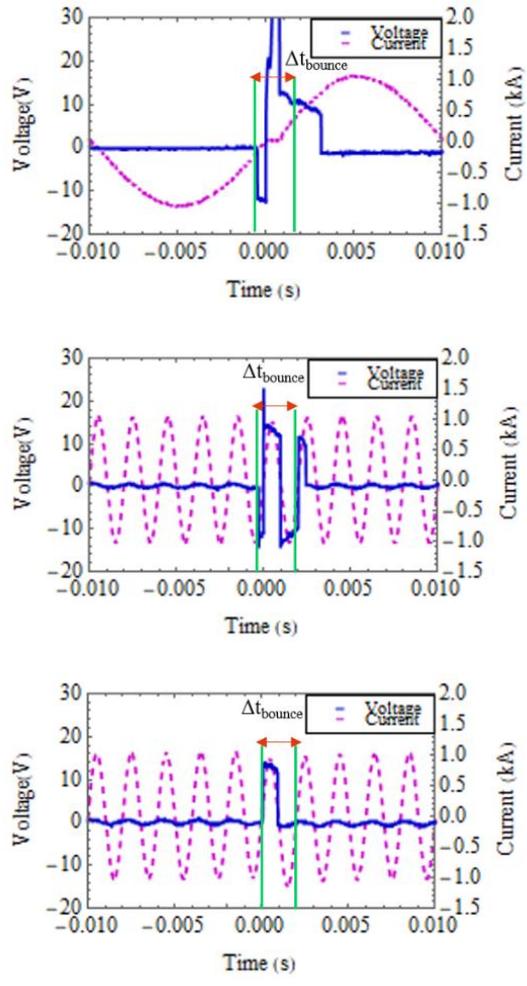


Fig. 7 a) & b) Example of reignition phenomenon at 50 Hz and 500 Hz respectively c) one ignition at 500 Hz

3.3 Bounce arc energy vs voltage frequencies

The arc energy W_{arc} has an important impact on the welding characteristics, the energy dissipated during arc time is [13] :

$$W_{arc} = \int_{\Delta t_{arc}} u i dt \quad (1)$$

- u : the voltage across the contact gap
- i : the current flowing through the contact

The bounce arc energies measured during the make tests are presented in Figure 8. The dependence of these energies with respect to the contact lifetime follow approximately the one of the welding force shown in Figure 3.

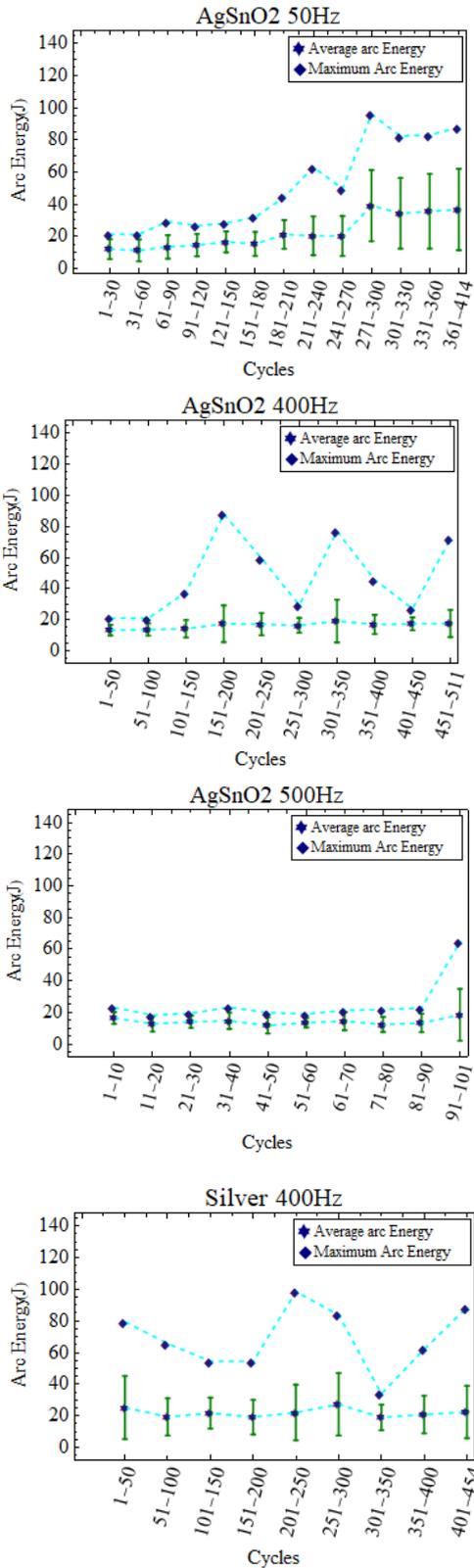


Fig. 8 Bounce arc energy vs. test cycles

The bounce arc energies are proportional to the arc duration, to the current level and the voltage level. In this case, the increasing of energies for AgSnO₂ samples especially in 50 Hz is explained by the damage of the contacts surfaces. This deformation increases the number of asperities, which provokes other arcs and implicitly increases the arc energy values (Figure 9). In addition, the high current (750 Arms) helps to maintain the arc longer and expand the arc duration.

3.4 Contact materials after the make test

After going through several arcing tests, a major change is observed on the contacts surfaces. Those damages are depending on the arc energy and the material nature as explained before.

Figure 9 shows the condition of those surfaces after the make tests

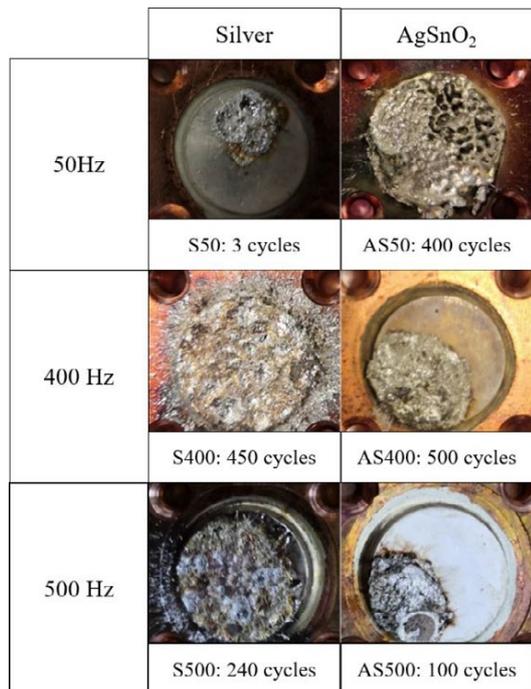
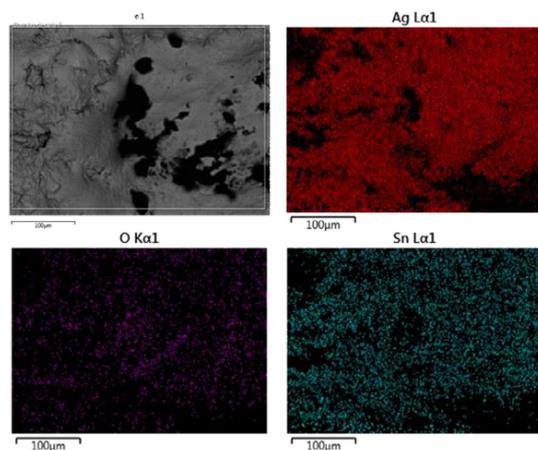


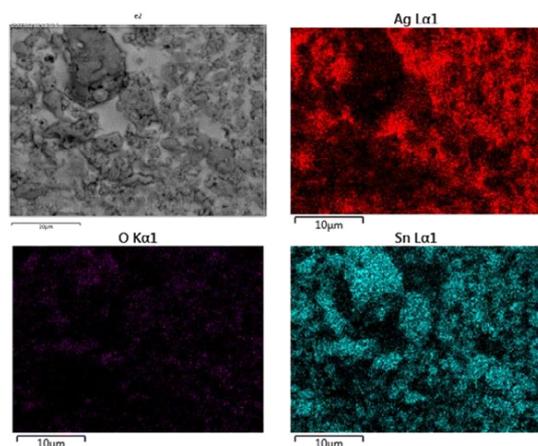
Fig. 9 Contacts surfaces after the make tests

The presence of pores on the surfaces of AgSnO_2 samples is referred to the presence of the metallic oxide on the contact material, they are created by gaseous bubbles of the metallic oxide in the silver matrix. This aspect is considered as an anti-welding mechanism [14]. The diameter of these pores varies between 1 mm and 10 μm . In addition to this, it is noticed that the arcs have reached all the surface of AgSnO_2 sample AS50 which is not the case for AgSnO_2 AS400 and AS500. Thus when the probability of arc occurrence increases on a small part of the sample, this leads to a local severe degradation, which could accelerate the occurrence of strong welding. Furthermore, Rieder et al. demonstrated that the more the molten zones of each electrode meet perfectly the more the welding force becomes higher [15]. This could explain the difference of the samples lifetimes.

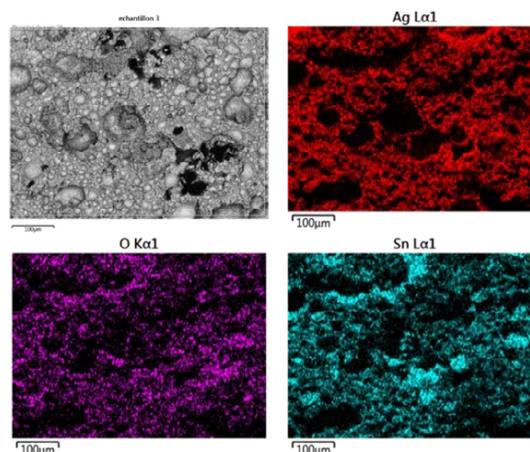
The silver samples are damaged differently from the AgSnO_2 ones. On their surfaces, a severe erosion had taken place by splattering the droplets of molten metal as observed on the surface of the contact holder.



a) MEB AgSnO_2 50 Hz



b) MEB AgSnO_2 400 Hz



c) MEB AgSnO_2 500 Hz

Fig. 10 Microstructure of AgSnO_2 sample with SEM – EDS. a) AS50 - b) AS400 - c) AS500

Figure 10 shows the surface roughness of AgSnO_2 contacts after finalizing the make tests, the images are obtained by using SEM. The EDX analysis have been used to show the chemical elements repartition on the contacts surfaces. It is found that the elements still almost homogenous even after all the arcing cycles. Furthermore, the tin oxide is more concentrated in the edges of the pores especially on the samples tested with 400 Hz and 500 Hz.

4 Conclusion

In this work, making tests were carried out for 115 V/ 750 Arms with different frequencies; 50 Hz, 400 Hz and 500 Hz. The purpose of this study was to analyse the effect of the voltage frequency on the bounce arc and the contacts welding characteristics.

According to an analytical approach, it was expected that increasing the voltage frequency could help to reduce the bounce arcs duration and consequently decrease the rate of welding occurrence and the welding force. However, the obtained results show that the voltage frequency has an indirect effect on welding characteristics because of the arc reignition.

That is, the arc reignition expands the arc durations and implicitly increases the arc energies. It has also an impact on the condition of contact surface. The number of arc reignition, characteristics of arc energy and the degradation of contact surface lead to high welding forces and increase the welding occurrence.

The results of this work open up further studies for the understanding of the physical interaction of arc reignition with the contact materials and its effects on their reliability in different electrical, mechanical and atmospheric conditions.

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