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Antimicrobial Performance of Different Metals

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Abstract. Health care associated infections or nosocomial infections (NI) is the fourth leading cause of disease and the most common complication affecting hospitalised patients in addition to a minimum of 175,000 deaths every year in industrialised countries. The Center for Disease Control and Prevention (CDC) states that influenza is transmitted from person to person primarily via large virus-laden droplets or through direct or indirect contact with respiratory secretions when touching surfaces contaminated with influenza virus and approximately 80% of the infections are transmitted via touch surfaces. In the year 2020 the Coronavirus (Covid 19) spread has affected the global community and also caused a great concern for the people and health care workers with a global infected population of more than five million.

With the ongoing population rise in the cities growing drug resistant bacteria, increasing infection rate in hospitals and communities, ageing world population strongly indicates the need to minimise the spread of infections via touch surfaces. Metals (and products manufactured from them) such as copper and silver are known to exhibit antimicrobial properties. These metals, or composites containing them, can be used as additives and incorporated into other materials such as paints, plastics and powder coatings to imbue these materials with antimicrobial properties.

In this paper we present the inherent antimicrobial properties of a copper containing alloy, two alloys of hospital grade steel (304 and 316), extruded aluminium (606013), anodized aluminium (606013) and zinc clad aluminium (3003-7072). Additionally, these materials were coated in epoxy resin powder coating with and without silver based antimicrobial additive. The ability of these metal alloys to reduce the population of inoculated microorganism numbers was assessed via the international standard (ISO) 22196:2011 Measurement of antimicrobial activity on plastics and other non-porous surfaces.

Introduction

Nosocomial infection or healthcare associated infections occur in a patient who is under the treatment of medical care in the hospital, but the infection was absent for the patient at the time of hospital admission. These infections affect the well-being of the patients, health care staff and may also occur after the patient is discharged from the hospital [1]. In the year 2020 the Coronavirus (COVID-19) spread has affected the global community and caused a great concern for the state and health care workers with a global infection of more than fifty million. The coronavirus spreads through the respiratory droplets and when these droplets are in contact with another person the infection spreads to the new persons. These droplets are airborne which potentially infect any person within a radius range of 1.5m. Another mode of transmission is these droplets land on a surface of any inanimate objects and subsequently touched by other person. Hence the World Health Organisation [2] recommended the handwashing and disinfection of the surface are vital to minimize the spread of the infection. This recommendation is strengthened considering that people touch their face on an average of 23 times per hour, with 44% of these occurrences involving the mucous membranes of the mouth and/or nose [3].

Health care associated infections or nosocomial infections (NI) is the fourth leading cause of disease and the most common complication affecting hospitalised patients in addition to a minimum of 175,000 deaths every year in industrialised countries [4]. The Center for Disease Control and Prevention (CDC) states that influenza is transmitted from person to person primarily via large virus-laden droplets of respiratory secretions. These droplets infect animate (people to people transmission) or inanimate (people -surface-people) surface via contact.[5] A study showed that approximately 80% of the infections are transmitted via touch surfaces [6]. A survey from OECD [7] countries from the impact of sick leave cost on economy shows 0.8% of EU GDP. An European survey [8] showed the total number of NI in European acute care hospitals was 3,2 million in 2011-2012.

Background

With growing global population thriving in the cities, growing drug resistant bacterias, Increasing infection rate in hospitals and communities and ageing world population, strongly indicates the need to minimise the spread of infections via touch surfaces. Despite the investments in health care and improved cleaning and hygiene process the Noscomical infection rates are increasing. To combat this problem, new antimicrobial metals or surfaces with antimicrobial coating are used in hospitals and public spaces. Traditionally in the hospitals the most common material used in door handles, bed rails, furnitures, medical cabinets, racks etc are made of stainless steel and are sterlised on a periodic basis. The main advantage of using the stainless steel is that this material can withstand all types of cleaning products. However, several studies have proven that the surfaces made by stainless steel become a breeding ground for the microbes [9].

Trends and drivers

The COVID-19 virus origninated in Wuhan province in China in late 2019 and on 30th January 2020, WHO declared the outbreak of the virus in China as a global pandemic. This outbreak forced several countries to shutdown non-essential economic activities which led to an economic downturn not even seen in 2008-09 financial crisis. The increased global travel levels also has raised the spread of COVID-19 to almost all the parts of the world. A recent study also suggest that there is no evidence in support or against the use of antiviral therapy or a specific antiviral agent with a majority of the COVID 19 infections are attributed due to the global travel [10]. The trends seen in NI and associated deaths, growing drug resistant bacteria in hospitals and communities are also increasing.

Certain metals and products manufactured from them are known to exhibit antimicrobial properties. These metals, or composites containing them, can be used as additives, and incorporated into other materials such as paints, plastics, and powder coatings to imbue these materials with antimicrobial properties as 80% of the infections are spread through a touch surfaces [6]. Among the different materials copper, silver and Zinc oxides are known to exhibit antimicrobial properties. The copper technology road map [11] has cited that copper may be used in emerging application such as an anti-microbial surface. The products that copper may be expected to replace are door handles, knobs, touch surfaces in schools, hospitals, public buildings, transports etc. There has been several research conducted comparing the antimicrobial performance of different materials such as copper, stainless steel, zinc, lead, brass tin etc. but there is a limited literature availability on the performance of aluminium on the bacteria or viruses. This paper presents a comparison of extruded aluminium, anodized aluminium, powder coated aluminium, zinc clad aluminium, copper sheet, stainless steel 304 and 316 grades used in hospitals.

Method

ISO 22196 (JIS Z2801- Japanese Test Method) is widely used to determine the antibacterial performance of the surfaces. The samples are prepared with 50mm x 50mm dimension and thickness less than 10mm. Figure 1 shows the test processs defined by the ISO 22196. In the first step (A) a known quantity of test organism is placed on to a treated and untreated sample. Normally three samples are taken to ensure the repeatability of the process. The loaded samples are covered with a microfilm (40mm x 40mm and thickness of less than 0,1mm) to ensure the humidity levels are maintained and incubated at 35 (±1) °C for 24 hours (B). After incubation the bacteria are recovered from the samples by washing off into a bag and the surviving bacteria is transferred for growth in petri dish (C). Finally, the antimicrobial performance is determined based on the number of bacteria initially placed and finally recovered (D).

In bacteriology, the bacteria are classified into two groups gram positive and gram-negative bacteria with a gram staining procedure, which differentiates bacteria based on the cell wall structure. Upon using a crystal violet dye on the bacteria, gram positive bacteria retain the violet colour and gram-negative bacteria do not retain and show it as either red or purple. To understand the efficacy of the material, ISO 22196 requires the test shall be conducted on both gram positive and gram-negative bacteria. The two bacteria used in the test are Methicillin-resistant Staphylococcus aureus (MRSA) refers to a group of Gram-positive and Escherichia coli (E-Coli) refer to the Gram-negative bacteria.

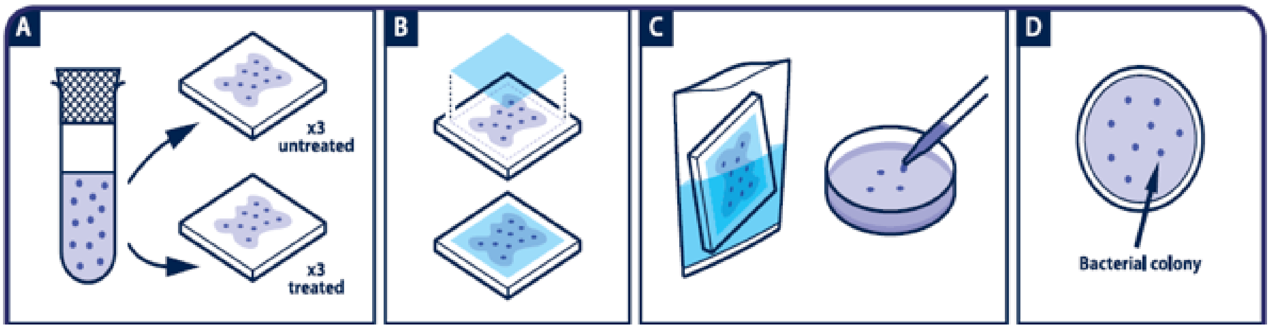

Fig.1. Test Protocol

Materials

The material selected for the test are shown in table 1. The extruded aluminium profile was made from 606013 alloy and zinc clad aluminium sheet comprised of 7072 clad on the outside and 3005 in the core and were produced by Norsk Hydro.

Table 1. Test materials

Material	Alloy/ grade	Major Content
Extruded aluminium	606013	Aluminium > 98.8%
Stainless steel	304	Fe>70%
Stainless steel	316	Fe>60%
Copper sheet	CW004A	Cu>99.9%
Powder coated extruded aluminium (with & without antimicrobial coating)	606013	Aluminium > 98.8%
Anodised extruded aluminium (with & without antimicrobial coating)	606013	Aluminium > 98.8%
Zinc clad aluminium (Zn 0,95%)	7072/3003	Aluminium > 97.8%

The extruded aluminium profile was 3 mm thick. The Zinc clad material was 0.4mm in thickness and consisted of a 3005LL alloy with a clad layer of 7072 alloy (approximately 40 microns) on one side and 4343 silicon clad on the other side. The material was tested only on zinc clad side. The power coating was done on two different process one with the normal powder coating and the second with Interpon powder coat (Antimicrobial product B55003 <10µM particle size, active substance silver phosphate glass). The thickness of the stainless-steel sheet (304 and 316 grade) used was 0,9mm and the thickness of the copper sheet was 1,5mm. The extruded aluminium sample was also analysed by Optical Emission Spectroscopy (OES) to validate the chemical composition and the OES result is shown in table 2.

Table 2. OES analysis of extruded aluminium samples

Element %	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Sample 1	0.5	0.2	0.01	0.05	0.37	0	0.01	0.02	Remaining
Sample 2	0.5	0.2	0.01	0.05	0.38	0	0.01	0.02	Remaining

Results- Test phase 1- Twenty-four hours exposure

According to the ISO 22196, the antibacterial activity is calculated using the equation (1). In simple terms, the antibacterial activity of the test sample is deducted from the controlled sample (which exhibits no antibacterial activity).

$$R= (Ut-Uo)- (At-Uo)= Ut-At \tag{1}$$

Where,

R is the antibacterial activity.

Uo is the average of the common logarithm of the number of viable bacteria in cells/cm^2, recovered from the untreated test specimens immediately after innoculation.

Ut is the average of common logarithm of the number of viable bacteria is cells/cm^2, recovered from the untreated test specimens after 24h

At is the average of common logarithm of the number of viable bacteria is cells/cm^2, recovered from the treated test specimens after 24h

Greater the R value, higher the antibacterial activity, although the standard do not prescribe any value the test lab conducted the test set an internal quality control percentage reduction requirement of 95% reduction of test organism.

The test results are summarized in table 3 after different materials are evaluated for antibacterial efficacy after 24-hour period. As expected, the anodized and powder coated aluminium samples did not show any antibacterial activity. However, extruded aluminium and zinc clad aluminium performed even better than the copper. Stainless steel 316 grade showed antibacterial efficacy on E coli bacteria but failed on MRSA and stainless steel 304 grade failed both on Ecoli and MRSA bacteria. Using this self-imposed standard of efficacy (>95%) we can consider stainless steel and anodized aluminium to have ‘failed’ this test. Extruded aluminium, copper sheeting and zinc clad aluminium all exceeded the 95% efficacy requirement.

Table 3. Antibacterial efficacy of different materials after 24 hours

Material	Ecoli “R”	Ecoli Result	MRSA “R”	MRSA Result
Extruded aluminium	≥99,99%	Pass	≥99,99%	Pass
Copper sheet	99,93	Pass	≥99,92%	Pass
Anodised aluminium	Growth	Fail	90,72	Fail
Powder coated aluminium	Growth	Fail	Growth	Fail
Zinc clad aluminium	≥99,99%	Pass	≥99,95%	Pass
Stainless steel 316	≥99,99%	Pass	91,79	Fail
Stainless steel 304	77,18	Fail	92,70	Fail

To validate the test results, the extruded aluminium, stainless steel 304 and copper were selected and tested in a different lab in parallel to the test done in the first lab. The test results are shown in figure 2 for Ecoli bacteria and figure 3 for MRSA, where 51883A represents extruded aluminium, 51883B represents 304 stainless steel and 51883C represent copper sheet. In this test for control sample, untreated polyethylene was used, and the antibacterial efficacy values are summarized in Table 4 and table 5 for E coli and MRSA bacteria respectively

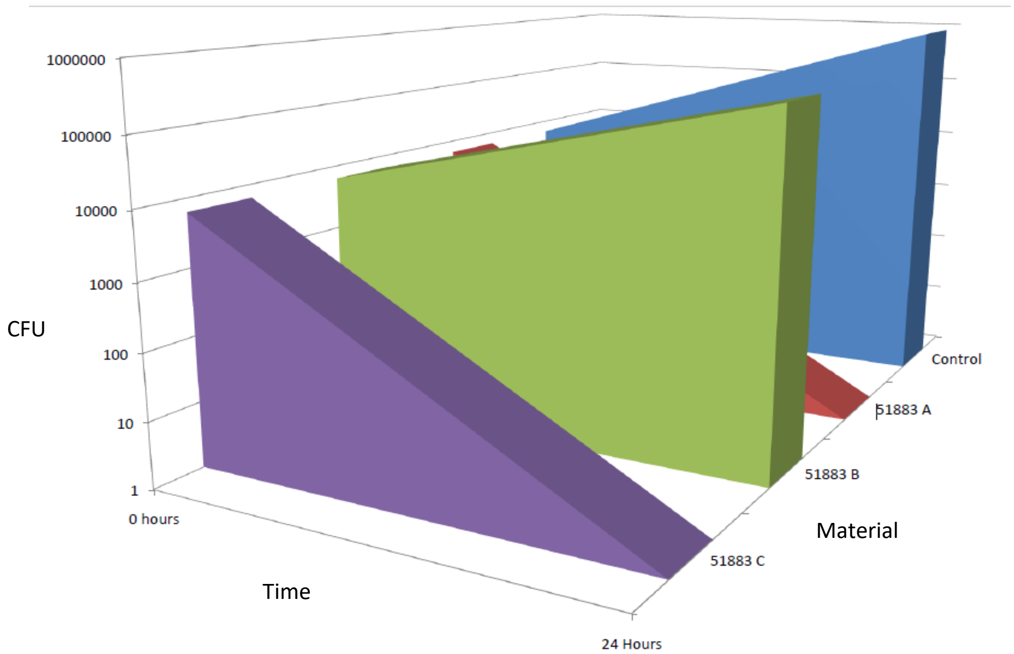

Fig. 2. Antibacterial efficacy of three different material against Ecoli bacteria

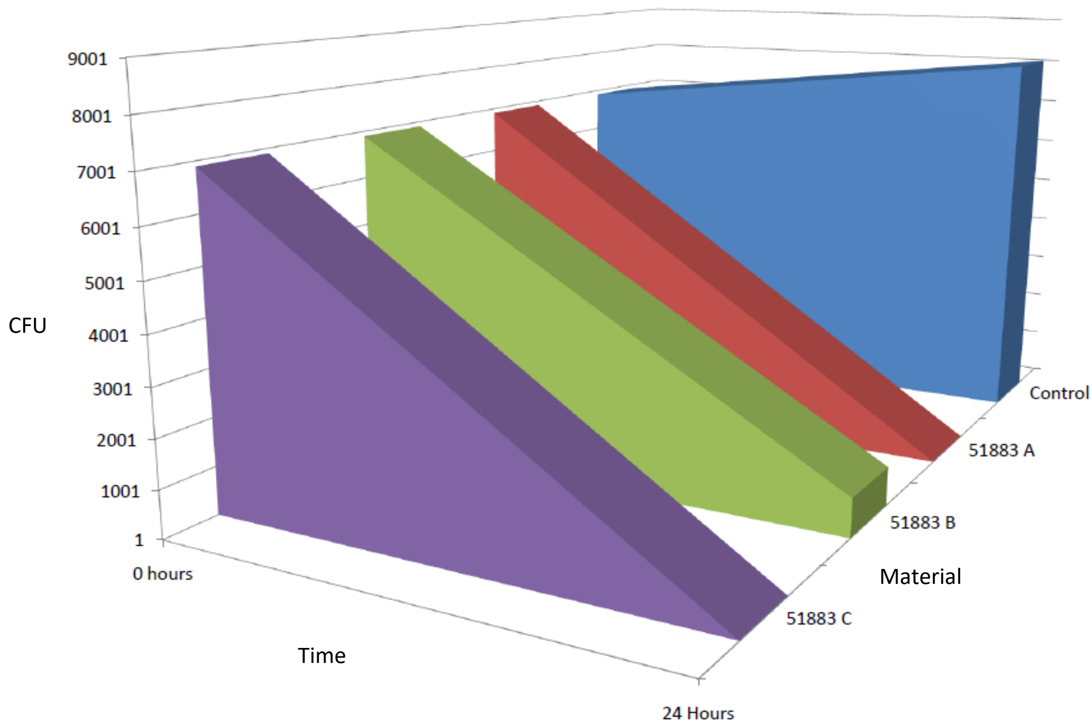

Fig 3. Antibacterial efficacy of three different material against MRSA bacteria

Table 4. Antibacterial efficacy of different materials against E coli after 24 hours

Material	Ecoli CFU 0hrs	Ecoli CFU 24hrs	E coli Reduction	Antibacterial efficacy test
Control	6300	880000	NA	Control
51883A- Aluminium	6300	1	>99.9999%	Pass
51883B- Steel-304	6300	260000	70.5% -growth	Fail
51883C- Copper	6300	1	>99.9999%	Pass

Table 5. Antibacterial efficacy of different materials against MRSA after 24 hours

Material	MRSA CFU 0hrs	MRSA CFU 24hrs	MRSA Reduction	Antibacterial efficacy test
Control	6900	8100	NA	Control
51883A- Aluminium	6900	1	>99.988%	Pass
51883B- Steel-304	6900	810	90% reduction	Fail
51883C- Copper	6900	1	>99.988%	Pass

The validated test results show the extruded aluminium performs as equivalent to copper in antibacterial efficacy, while stainless steel 304 grade do not show any such effect.

Results- Test phase 2- Four hours exposure

Having demonstrated potential antimicrobial effects for all metal surfaces examined, we started to investigate when these properties might manifest, initially with a four-hour exposure of organism to surface, followed by the standard 24-hour incubation of survivors. For metals, the results are shown below in Table 5. The extruded aluminium samples, zinc clad aluminium sample and copper sample exhibited antibacterial efficacy after four hours of exposure to Ecoli, whereas the test results were aborted for Copper sheet and stainless steel 316 grade for MRSA bacteria due to test issues.

Table 5. Antibacterial efficacy of different materials after 4 hours

Material	Ecoli “R”	Ecoli Result	MRSA “R”	MRSA Result
Extruded aluminium	95.53%	Pass	99.78%	Pass
Copper sheet	95.95%	Pass	*	-
Anodised aluminium	Growth	Fail	40.15%	Fail
Zinc clad aluminium	99.95%	Pass	≥99.95%	
Stainless steel 316	84%	Fail	*	-

* Test aborted

Results- Test phase 3- Twenty-four hours exposure -Antimicrobial surface coatings

In the phase three of the test, the aluminium samples were powdered coated and anodised with and without antimicrobial coating and tested after 24 hours of exposure to the bacteria. Powder coating of all samples was performed by Akzo Nobel, utilizing a variant the Interpon powder coat with and without silver based antimicrobial additive. In addition, a special anodized process that incorporates antimicrobial layer on the surface was also tested. Table 6 shows the results of the antibacterial efficacy of powdered coated and anodized aluminium samples after 24 hours. The antimicrobial coated samples exhibited a good antimicrobial efficacy while the normal powder coated samples exhibited growth and failed the efficacy test. Similarly, the special anodized process also displayed antimicrobial efficacy.

Table 6. Antibacterial efficacy of powdered coated and anodized aluminium samples after 24 hours

Material	Ecoli "R"	Ecoli Result	MRSA "R"	MRSA Result
Extruded aluminium-Powder coated	Growth	Fail	Growth	Fail
Extruded aluminium-With antimicrobial powder coat	99.5%	Pass	99.5%	Pass
Anodised extruded aluminium-Powder coated	Growth	Fail	Growth	Fail
Anodised extruded aluminium-With antimicrobial powder coat	99.5%	Pass	99.5%	Pass
Anodised extruded aluminium	Growth	Fail	90.72%	Fail
Antimicrobial -Anodised extruded aluminium	99.51%	Pass	99.99%	Pass
Zinc clad aluminium-Powder coated	Growth	Fail	Growth	Fail
Zinc clad aluminium-With antimicrobial powder coat	99.5%	Pass	99.5%	Pass

Results- Test phase 4- Four hours exposure--Antimicrobial surface coatings

In the phase four of the test, the aluminium samples were powdered coated and anodised with and without antimicrobial coating and tested after four hours of exposure to the bacteria. Powder coating of all samples was performed by Akzo Nobel, utilizing a variant the Interpon powder coat with and without silver based antimicrobial additive. In addition, a special anodized process that incorporates antimicrobial layer on the surface was also tested. Table 7 shows the results of the antibacterial efficacy of powdered coated and anodized aluminium samples after 4 hours. The antimicrobial coated samples exhibited a good antimicrobial efficacy while the normal powder coated samples exhibited growth and failed the efficacy test. Similarly, the special anodized process also displayed antimicrobial efficacy. As more than planned samples were used in earlier test, test with MRSA bacteria within four hours could not be completed except for anodized aluminium with and without antimicrobial surface. It should be noted that all these tests were done in 2013-14 before theCOVID19 outbreak.

Table 7. Antibacterial efficacy of powdered coated and anodized aluminium samples after 4 hours

Material	Ecoli "R"	Ecoli Result	MRSA "R"	MRSA Result
Extruded aluminium-Powder coated	Growth	Fail	NA	NA
Extruded aluminium-With antimicrobial powder coat	99.87%	Pass	NA	NA
Anodised extruded aluminium-Powder coated	Growth	Fail	NA	NA
Anodised extruded aluminium-With antimicrobial powder coat	99.87%	Pass	NA	NA
Anodised extruded aluminium	Growth	Fail	40.15%	Fail
Antimicrobial -Anodised extruded aluminium	> 99.99%	Pass	99.99%	Pass
Zinc clad aluminium-Powder coated	Growth	Fail	NA	NA
Zinc clad aluminium-With antimicrobial powder coat	99.87%	Pass	NA	NA

Discussion

In the last few years there has been several publications promoting copper has an antimicrobial material; 99.9% pure copper can eliminate bacteria in one hour but for copper with 60% content requires more than two hours to achieve the similar antimicrobial activity [9]. Aluminium alloy do exhibit antimicrobial activity as seen in the study. It is not clear what causes the antimicrobial effect in aluminium alloy, is it the presence of 0,01% copper and 0,01% Zinc that promotes antimicrobial effect? Hypothetically, the presence of traces of copper and zinc in aluminium alloy will not have that significant effect on antimicrobial efficacy as we see a big difference in antimicrobial efficacy between 99.9% copper and 60% copper. In addition to the chemical composition influence, the physical characteristic of the surface also as an impact on the antimicrobial efficacy [12]. One such parameter is the wettability, which depends on the surface roughness. High contact angles (>65) are recommended for antimicrobial application as these surface inhibit cell attachment as they are attributed to hydrophobic behavior and do not promote adhesion properties. The bacteria are laid on the surface and they are primarily in contact with the surface layer of metals such as aluminium, copper and zinc which are typically oxides. Studies have shown the oxide layer of copper has detrimental effect on cell wall of the bacteria [13]. The antimicrobial behaviour of other metal oxides is also of interest, but studies are very scarce. Most consider oxidation on particles/nanoparticles and therefore it is difficult to assess whether the antimicrobial performance is caused by the oxides or particle size [9].

In this study the antimicrobial performance of different metals was studied, and it can be seen extruded aluminium alloy 606013 showing a good antimicrobial efficacy. Further work should focus on understanding the effect of metallic oxides and metal ions on the antimicrobial efficacy. In this study only two bacteria families were looked into MRSA (gram positive) and E.Coli (gram negative); other microbes should also be explored to have a broader understanding of the performance of aluminium alloys against these microbes. Touch surfaces are typically cleaned once every day, but many individuals touch the surface quite often, it is important to understand the antimicrobial efficacy of the different metals and coating on short intervals such as 10 minutes, 20 minutes etc and also simulating different environments such as temperatures, humidity and repeated touch exposure on

the surface. It should be noted that the test was carried out in laboratory environment, Further work can also focus on comparing the performance of different metallic touch surface in the real day to day environment.
Although the touch surface products are showing good antimicrobial efficacy, it is important to maintain daily hygienic practice such as day to day cleaning of the metallic surfaces. There is also a lack of information about the effect of corrosion of touch surface products with antimicrobial behaviour (there is neither information about the effect of direct contact between cleaning products and microbes nor the effect of cleaning products on the chemistry change of cleaned surfaces) [9]. It is also important to understand and provide recommendations on the appropriate cleaning products for different materials to ensure the antimicrobial performance are maintained.

Conclusion

Eighty percent of the infections are transmitted via touch surface and with metallic touch surface being widely used in hospitals, transportation, public places etc. they seem to be a menace to control the infection spread. The study showed potential benefits of using extruded aluminium, powder coated aluminium (with antimicrobial coating) and special anodised aluminium (with antimicrobial layer) all having a good antimicrobial efficacy. It should be noted with the current LME pricing the weight for weight the aluminium products will cost only a third of touch surface made by copper.

2020 COVID 19 situation showed the need for minimizing the spread of infection via touch surfaces and the need for products that show antimicrobial efficacy in public places. Even if the infection rate is reduced by 10%, the positive impact on lives saved and on nation's economy is high. With recycled aluminium such as Hydro CIRCAL, the touch surfaces produced from recycled aluminium promotes sustainability and as well as the well-being of the people.

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