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Environmental Aspects of Lead Free Soldering and Study of Legislations Banning Lead Based Solders in Different Countries

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Abstract

Lead based solders have been in use for many years, but in recent times, they are being phased out. Lead based solders have generated environmental problems and the dissolved lead in soil is also poisonous and carcinogenic. This being the case, lead is being phased out in most countries. This paper is a review on the problems faced due to lead based solders and the legislations undertaken in various countries to tackle this problem. Legal steps have been taken in developed countries and some steps have been taken in India too. Legislations in USA, European Union, Japan and India have been discussed. A detailed view of legislations in different countries is discussed and the way forward is outlined.These steps would help to ensure that our environment is kept cleaner. It is hoped that these legislations would force researchers to discover more and more lead free alloys in the future.

Keywords: Environment; Lead; Soldering; Legislation; Carcinogen; Lead free soldering

Introduction

Lead based solders are getting phased out in a gradual manner due to the health hazards posed by lead. It is important to study the steps taken in various countries in this regard. Stronger legal options to ban lead based materials will encourage research on lead free solders and other lead free materials. The natural environment contains the highest concentrations of lead of any heavy metal or hazardous chemical. Evidence of its use can be found all throughout history due to the significant physicochemical properties that it possesses. It is a global environmental chemical with high usage and potential for harm (Mahaffay et al., 1990; Riaz et al., 2023; Kaur et al., 2023; Hassan and Mohammed, 2023; Langat et al., 2024; Singh and Puri, 2023). It is tough to give up lead utilizing it because of its major features like softness, malleability, ductility, weak conductivity, and resilience to corrosion. It is not biodegradable, and as its use continues, its concentration in the environment rises, bringing with it a plethora of problems. The majority of human lead exposure is caused by leaded gasoline, smelting and burning lead, making pottery, building boats, painting with lead-based paint, using lead-based pipes, recycling batteries, grids, the arm manufacturers, colourings, and photocopying books.

Many countries are reducing reliance on lead and passing legislations. It is still employed in many different applications, including automotive maintenance, the production of batteries and recycling of spent batteries, metal refining and smelting, and many more. Lead is a highly carcinogenic substance that can damage almost all of the body's organs. Children and adults who are exposed to lead are most likely to have problems with their nervous systems. However, the poison has a more severe effect on kids than grownups. This is because their internal and external tissues are more malleable than those of fully grown humans.

Long-term exposure in adults may lead to poorer performance on a battery of tests designed to evaluate their brain health. Young children are particularly susceptible to the adverse consequences that might result from lead exposure, which can manifest as behavioral problems, academic struggles, and even a lowered IQ. Lead poisoning is associated with anaemia and hypertension, especially in the elderly and middle-aged. It was shown that both adults and children who were exposed to lethal levels of lead had significant harm to their brains and kidneys. The risk of having a miscarriage increases if a pregnant woman is exposed to high levels of lead. Male fertility was reported to be impaired by chronic lead exposure (Sokol and Berman et al., 1991). Lead toxicity typically causes blood troubles and nervous system harm.

Potential cause of lead poisoning

Lead poisoning is typically caused by taking in lead-contaminated water or food. Lead poisoning can also be caused by the unintentional consumption of dust, soil, or paint containing lead. Some organs, such as the immune system, cardiovascular system, central nervous system, and kidneys, may be negatively impacted by lead's ability to enter the circulation and circulate throughout the body (Bergeson et al., 2008). Most pharmaceutical companies recommend avoiding lead consumption above 1.0 g/g daily; yet, even this small amount of lead is bad for people over time. Lead exposure at work also plays a role. Girls who have high blood pressure often experience a puberty onset that is later than their peers (Schoeters et al., 2008).

When it comes to lead in the blood, there is no such thing as a safe level below which it is not a health risk. Extremely low but ongoing lead exposure has been linked to deterioration in children's cognitive ability (Needlemann et al., 1990). The use of lead in paints has significantly decreased over the past few decades as a direct result of the elevated lead poisoning dangers posed by paint pigments, particularly to youngsters. However, considerable concentrations of lead paint may still be found in older dwellings (Levin et al., 2008). Unwittingly, this could expose some children to lead. Although sales of white lead paint were discontinued long ago in developed countries, yellow lead chromate is still widely used. If you need to get rid of old paint, don't sand it off because the dust is very combustible (Marino et al., 1990). Heavy metals like lead have been found in certain traditional medicines. Several health problems have been reported as possibly being related to the use of traditional medicines (Karri et al., 2008). Many people feel that Ayurvedic medicines are extremely tainted with metals. Researchers recently looked at how much lead was in the blood of those who regularly take Ayurvedic medication. Blood lead levels were elevated by at least 10 g/dL in 40 of the 115 subjects, and by 50 g/dL in 9.6 % (Breeher et al., 2015).

Due to lead poisoning, dysplastic changes in erythroid precursors were recently observed in a patient who had been treated with traditional Chinese medicine (Lv et al., 2015). Also, the Centers for Disease Prevention and Control have issued guidance for the use of some traditional medicines that have been found to have high levels of lead and may expose people to lead or lead compounds. Daw Tway, for example, is used to help with digestion in both Thailand and Myanmar (Burma). Lead levels in Samples of Daw Tway had as much as 970 ppm. As much as 7,100 ppm of arsenic was found in the Daw Tway samples. Produce grown on lead-contaminated soils poses a health risk if consumed. Elevated lead levels in the soil are caused by a number of factors, including pipes with lead, paint with lead, and pollution from lead in gasoline used before the law from the Environmental Protection Agency in the 1980s. To prevent lead poisoning in the general population, one of the most effective ways to prevent exposure is to inform individuals about the most common risk factors. Lead poisoning is commonly seen in households due to lead water pipes (Moore et al., 1977). When lead is ingested, it is absorbed by the body at a rate of about 20-70%; children absorb it at an even higher rate. However, inorganic lead absorption through the skin is negligible.

Effects of Exposure to Lead

Lead poisoning has a long history of being associated with serious consequences. Lead poisoning can be caused by acidic fruit juices leaching lead salts used in pottery glazes. Several reports have addressed Beethoven's passing. Many of them have come to the conclusion that his doctor's usage of toxic quantities of lead-based medicine was the cause of his demise. Lead levels in his hair were discovered to be quite high after an analysis (Mai et al., 2006). During the 18th and 19th centuries, it was thought that lead was added to wine in secret to make it sweeter and make it look like new (Mai et al., 2006). The widespread use of lead acetate as a sweetener in Roman wine is widely believed to have contributed to widespread poisoning and ultimately the decline and fall of the Roman Empire. A lot of Roman emperors supposedly got dementia from using them for so long.

Usage of lead leads to inhibition of ferrochelatase and porphobilinogen synthesis. Lead prevents the formation of porphobilinogen protoporphyrin IX, and the addition of iron to it, leading to anaemia in many people. Microcytic anaemia develops when heme production is either blocked or ineffective (Cohen et al., 1981). One of the ways in which lead impairs cognition is through the interactions it has with ion channels, as it behaves as a calcium analogue and disrupts their normal function. At physiological doses, Pb^{2+} blocks voltage-dependent calcium channels in a robust, selective, and reversible manner (Busselberg et al., 1993). Recent research has shown that sodium selenite mitigates the toxic effects of lead nitrate on the blood cells of rats. They also demonstrated that diabetic rats were more adversely affected by lead nitrate than were rats without diabetes (Bas et al., 2015). The results of a study conducted on oxidative stress in first-grade Uruguayan pupils who were exposed to low levels of lead indicate that there may be effects that are bad for oxidative stress (Roy et al., 2015). The workers who were exposed to lead had trouble breathing, and their blood levels of lead and zinc protoporphyrins were elevated (Jurdziak et al., 2015).

Multiple United States (US) law enforcement agencies recently recovered counterfeit cigarettes that tested positive for both lead and cadmium following an investigation into their origin. The levels of lead and cadmium were found to be much higher than in their natural forms. This research suggests that there may be a link between the use of counterfeit cigarettes and adverse public health outcomes (He et al., 2015). As a result of these and other concerns, governments around the world have passed laws banning or severely limiting the use of lead. Various laws from throughout the world are discussed below.

Legislations using lead-based solders

Lawmakers have been drafting legislations since 2006 in order to safeguard the environment. This led to manufacture of lead-free solder alloys (Chi et al., 2020). Since the turn of the century, traditional solder alloys containing lead have seen extensive use thanks to their high quality and low price. Solder alloys that are lead-free, most of which are based on the SnZn, SnCu, SnAgCu, and SnBi systems, are in high demand, however, due to restrictions on the use of hazardous materials in electrical and electronic products through the Waste Electrical and Electronic Equipment (WEEE) Directive (RoHS Directive) (Olson et al., 1993).

But thermal/electrical stress and corrosive environments have a bigger effect on lead-free solders, and their use has been limited because they are less reliable. This is because lead-free solders have a lower melting point (Wang et al., 2019). When it comes to electronics, high-performance lead-free solder materials are needed. The European Union (EU) expedited the switch to products without lead by publishing two directives in official gazettes on 13th February 2003: both The Waste Electrical and Electronic Equipment (WEEE) directive and the Restriction of Hazardous Substances (RoHS) directive are both examples of directives (Jiang et al., 2019). Due to regulations banning the use of ecologically harmful elements and increased awareness of the issue, lead in electronic equipment has been effectively banned. The current electronic industry has developed lead-free solders as an alternative to Sn-Pb solders (Liu et al., 2019).

Environmental and health risks due to lead-containing solders have forced regulations like WEEE and RoHS. Directives have been passed to encourage the electronic packaging industry to use lead-free solders instead of lead-based ones (Wu et al., 2019). Lead based solders are used in Industry that makes electronic packaging, due to the desirable properties like a low melting point, being easy to wet, and being reliable. Since the Restriction of Hazardous Substances (RoHS) was made, it has been almost impossible to use lead-based solders (Tian et al., 2018). For the last 50 years, SnPb solder has been utilized for electronic assembly due to its superior soldering properties, ease of manufacture, dependability, and cost. Nevertheless, lead is exceedingly hazardous to human health. Consequently, SnPb solder has been eliminated from consumer devices sold in the European Union (EU) and worldwide, including the US, China, Japan, South Korea, and Turkey (Shunfeng et al., 2016). Initially, this was a response to end-of-life disposal rules and the RoHS Directive of the European Union, which limits the use of dangerous substances.

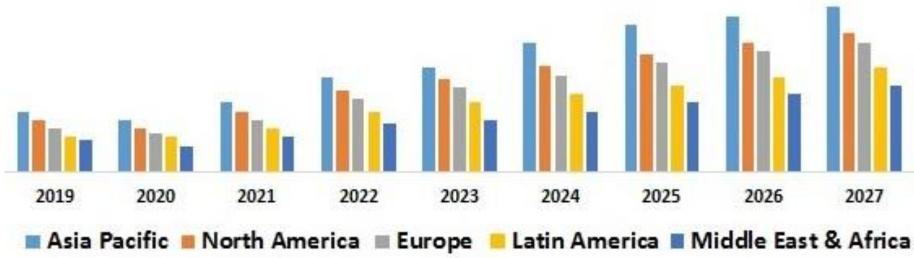

Fig. 1. shows the global lead-free solder balls market (2019-2027; US$Mn)

Data from Figure 1 shows the importance of lead-free solders in the world market and legislations have become absolutely necessary to bring in lead free solders in a big way.

Legislations regarding use of lead solders in various countries

Legislation in United States

According to a group of researchers (Althaf et al., 2021). Utilizing material flow analysis, highly resolved data on sales of electronic devices, and material composition, this study is an in-depth look at electronic waste in the United States. The main point of the study is to find out how e-waste affects the environment. Even though people think that mobile devices are making more e-waste, the amount of e-waste in the stream is going down (10% from the high that was expected in 2015) Large, old items like cathode ray tube TVs are being phased out. Changing consumer electronics material composition reduces toxicity concerns over lead and mercury while increasing dangers from scarce metals and device designs that hinder recycling.

California passed a legislation requiring electronic trash recycling, but it didn't ban lead in consumer devices. California's 2003 Electronic Trash Recycling Act subsidizes the collection and recycling of certain electronic garbage. The Covered Electronic Waste (CEW) Recycling Program is meant to help people in California get rid of their old electronics in a safe way. As of yet, there is no federal law prohibiting using lead in electronics in the United States. The majority of major electronics manufacturers throughout the world, Because of the new rules, companies, including those in the US, are looking harder for alternatives to lead-based solders. There have been two primary areas of focus for these efforts: lead-free metals and electrically conductive adhesives (Li et al., 2005). California and New Jersey, both located in the United States, are currently investigating the possibility of passing legislation that would mandate the recycling of electronic waste and the decrease of the amount of lead contained in products. In September of 2003, California Senate Bill 20, sometimes referred to as the Electronic Recycling Act of 2003, was submitted for consideration. The original implementation date for this law was January 2007, however it was delayed due to questions over who would be in charge of collecting and recycling electronic waste (Pecht et al., 2004).

Legislation in China

The People's Republic of China's Ministry of Industry and Information Technology passed the following laws: in the following order: 42. In 2006, which went into effect on March 1st, 2007. Products in the electronics industry are not allowed to contain any of the known hazardous compounds such as lead, cadmium, or chromium six plus (Rödel et al., 2015). Products sold in the European Union that contain any of the six compounds that the EU's RoHS directive says are dangerous cannot contain them. must feature a warning label: Lead, mercury, chromium VI, cadmium, PBB, or PBDE are all toxic chemicals. "Measures for the Administration of the Control of Pollution by Electronic Information Products" was released on February 28th, 2006, by the Chinese Ministry of Information Industry and other groups working together. They entered into force on March 1st, 2007. The purpose of labelling requirements and substance limitations is to compel enterprises to disclose and reduce their use of potentially hazardous substances. (Herat et al., 2008).

China has embraced the lead-free transition as a manufacturing hub for the electronics sector. The Chinese Ministry of Information Industries (MII) issued a lead-free electronic industry standard in 2003, mirroring comparable regulations in Europe. A group of researchers (Pecht et al., 2004) came to this conclusion. China is one of the exporters of E waste from its country (Bell et al., 2018) mentioned in his research as Higher-income countries have a history of exporting the issue to underdeveloped countries (e.g. Nigeria and Ghana). Between 2015 and 2016, the United States, the European Union, and China supplied Nigeria with approximately 60,000 metric tonnes of used electrical and electronic equipment. Approximately 26% of these shipments had defects. Several studies have found that children who live close to e-waste landfills had greater rates of lead poisoning in their blood.

Legislation in Japan

In the European Union and other regions, legislation that is formally referred to as "Restriction of Hazardous Substances (RoHS)" and colloquially referred to as "Lead Reduction in Electrical and Electronic Equipment" (RoHS/RoHS-RoE) has been passed to require that lead be taken out of all Electrical and Electronic Equipment (EEE). The goal of these kinds of laws is to make "Green Electronics" by ensuring that EEE is designed and manufactured with environmental considerations in mind. One of the main reasons for the regulation requiring manufacturers and researchers to develop viable lead-free alternatives to the conventional leaded solders used for many years is lead-free soldering in EEE (Herat et al., 2008). On July 1st, 2006, J-Moss or JISC0950 is Japan's version of the Restriction of Hazardous Substances in Electronic Equipment (RoHS), and its implementation required a modification to Japan's Law for the Efficient Utilization of Resources. Electronic device manufacturers who produced specified categories of goods that were sold after July 1st, 2006, are required by this law to give information about the kinds of materials they were made with. The Japanese Electronics Sector Development Association (JEIDA) has made a plan for the whole industry to switch to lead-free soldering. JEIDA additionally suggested 96.5Sn/3Ag/0.5Cu and 99Sn/8Zn/3Bi, 48Sn/57Bi/1Ag, and 96.5Sn/3Ag/0.5Cu. Many Japanese businesses have made the switch to lead-free products in an effort to differentiate them while also being environmentally conscientious. The Japanese government's MITI agency has mandated a reduction in lead usage in automobiles by a certain date (Pecht et al., 2004).

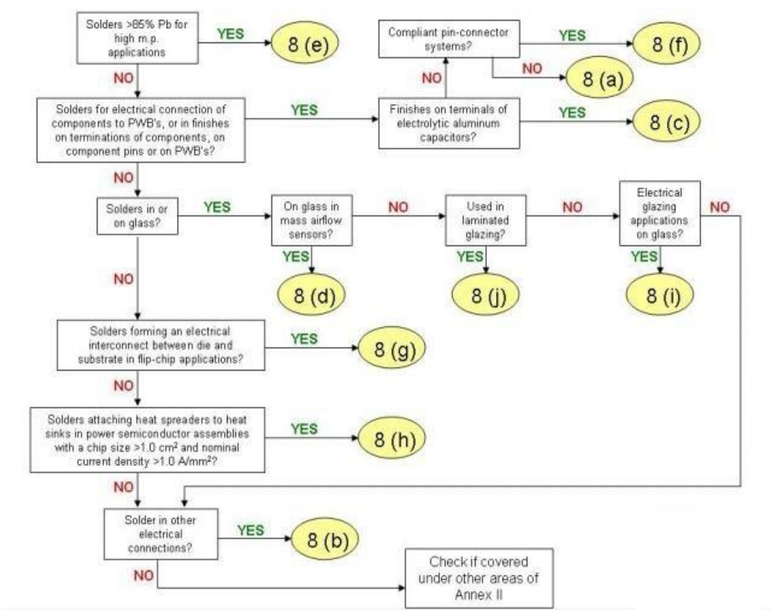

Fig. 2. showing a flowchart that helps in monitoring lead free legislation

Legislation in India

India passed legislation banning NGO's have put limits on the use of lead paint, but tests show that these rules are not always followed, particularly in underdeveloped nations (Rodel et al., 2015). Rule on Lead content in household and decorative paints, 2016. It warns that starting on November 1st, 2017; the amount of lead in paints should not be higher than 90 ppm. There have been difficulties, though. Even after the limits on the use of lead in paints entered into force in November 2017, Toxics Link's research investigations from the years 2018, 2019, and 2020 have shown that the country's execution of the rules has been subpar. According to toxics link study investigations, there hasn't been much of an improvement in the overall situation across the nation.

Conclusion

The world is moving towards sustainable manufacturing and lead-free solders are a step towards this end. It is hoped that the legislations that are being carried out in different countries lead to a situation wherein new lead-free alloys are developed. This step is already in practice with more and more lead-free solders being discovered.

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AJS and DA conceived the concept, wrote and approved the manuscript.

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