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## INFLUENCE OF LEAD'S CHARACTERISTICS ON ITS APPLICATIONS

Lead is a fascinating metal and one that definitely presents a challenge to the engineer and designer. It probably has more varied fields of application than any other metal, and these applications depend upon a broader variety of properties or characteristics than is usually the case among metals. For instance steel is usually used because of its strength, copper for its electrical properties, aluminum and magnesium for their lightness, but no one property of lead can be singled out as being responsible for the preponderance of its usage.

In fact roughly one-third of all the lead used is in the form of chemical compounds. These include such various compounds and applications as white lead and red lead in paint, litharge and red lead in storage batteries, litharge in oil refining, ceramics and varnishes, lead arsenate in insecticides, the lead chromates in color pigments, tetraethyl lead in high octane gasoline, lead azide in explosives, lead silicate in glases, and lead acetate for many things, to mention only some of the more important lead compounds.

Still larger tonnages of lead are employed in metallic form either alone or as alloys. In most of these applications the physical properties determine whether the metal is used, and if so, just how it is employed. They govern its selection and dictate design.

Among the outstanding characteristics of lead are weight, density, softness, malleability, flexibility, low melting point, low ultimate tensile and creep strength, low elastic limit, an ability to alloy with certain other metals in almost any proportion and an inability to alloy with others, self-lubrication, low electrical and heat conductivity, relatively high coefficient of thermal expansion, and above all, high corrosion resistance under a wide variety of conditions. Lead is usually selected for use because it has one of more of these characteristics. The design of the product or installation, however, must also take into consideration the other properties in many instances.

Before discussing these characteristics in detail, a brief general description of the lead industry, where lead comes from and what it is used for, may be both interesting and helpful.

Historically lead is one of the oldest known metals. It is mentioned in Exodus and elsewhere in the Old Testament. It was used to glaze pottery, to make solder and ornamental objects in the days of the Pharaohs. Old lead pipes have also been found in Egypt. In ancient India red lead was used as a cosmetic and the metal was used for weights, purifying silver, and as a monetary medium. The floor of the hanging gardens of Babylon was lined with sheet lead, and it was also used by the Babylonians for calking bolts into masonry.

In 2000 B. C. the Chinese made their first money of lead, and when silver coins came into use later, the government forbade working the lead mines to stop counterfeiting. It would certainly cripple modern industry if the lead mines stopped in order to keep a few lead slugs out of slot machines. Bronze coinage of ancient Greece and Rome contained from 3 to 30% of lead.

The Romans had a well established lead pipe manufacturing industry, making it in 15 standard sizes and standard 10-ft. lengths. Roman baths were also often lined with sheet lead.

Lead has always been an important article of warfare. Modern bullet cores and shot were preceded by leaden projectiles hurled from ships, and molten lead and great solid chunks of lead descended upon invaders from the battlements of besieged cities. Even Roman gladiators used lead knuckles to give their punches more authority.

In a little lighter vein, if you can say that of lead, Nero is said to have worn a lead plate on his chest to preserve his voice when singing, I imagine to reduce vibration. And going to the other extreme, Philetus, a teacher of Ptolemy Philadelphus, was so thin that he wore lead soled shoes to keep from being blown over. And, in passing, Greek gamblers used lead-loaded dice. There is nothing new under the sun.

The United States is the world's greatest producer of lead. In addition to the biggest mine production in the world, we also are producing about a third of our needs from scrap. The biggest single lead consuming industry is the storage battery industry and no other country approaches us in the use of automobiles and consequently storage batteries, so that is a big additional lead mine wherein 80% of the lead used in the first place is eventually recovered as scrap and re-refined.

Briefly the other countries which are big lead producers are Mexico, Canada, Australia, Peru, the Argentine, and certain European countries such as Silesia and Yugoslavia. In this country Missouri, not ordinarily thought of as a mining state, is the biggest producer, followed by Idaho and Utah.

Some guide to the usefulness and properties of lead may be gleaned from a broad analysis of the amount used for various purposes. These figures give you roughly a comparison between a wartime and last year, a peacetime year. You will see that in general the peacetime uses of lead are also the war-time uses, with some variation due to the extraordinary demand for lead for such emphatically wartime applications as ammunition and high octane gasoline.

**Estimated Lead Consumption***

| | 1944 | 1946 |
|---|---|---|
| Storage Batteries | 297,095 | 252,060 |
| Cable | 126,945 | 93,275 |
| Paint and Varnish | 98,500 | 78,320 |
| Ammunition | 50,555 | 30,125 |
| Oil Ref. and Gasoline | 94,670 | 60,270 |
| Construction | 103,240 | 110,045 |
| Insecticides | 24,185 | 26,095 |
| Printing | 22,575 | 33,945 |
| Foil | 16,070 | 3,640 |
| U. S. Government | 5,730 | 130 |
| Ceramics | 7,370 | 6,595 |
| Colors | 12,560 | 13,840 |
| Railroad | 26,785 | 22,325 |
| Automobile | 7,740 | 16,715 |
| Cans | 10,310 | 10,480 |
| Steel-Wire | 4,575 | 3,425 |
| Collapsible Tubes | 16,256 | 13,135 |
| Rubber & Hose | 4,135 | 4,000 |
| Coatings | 5,500 | 3,615 |
| Brass Manufacturing | 5,455 | 4,245 |
| Lead Head Nails | 500 | 1,615 |
| Seals | 1,670 | 820 |
| Abrasives | 590 | 500 |
| Powder | 1,440 | 905 |
| Misc. Chemicals | 4,095 | 2,010 |
| Unclassified | 124,960 | 116,710 |
| TOTAL | 1,073,506 | 908,710 |

* Source - Lead Industries Association

Now let's examine the properties of lead and how they are applied industrially and the precautions that must be taken to use lead most advantageously without getting into pitfalls.

Corrosion resistance is probably the outstanding characteristic of lead, so I believe that should be discussed first and at considerable length, if you'll pardon me. Corrosion resistance is either the main or a contributing factor in the selection of lead for such important things as cable sheathing, pipe, roofing and flashing, coatings on steel and other metals, and, of course, chemical equipment. Lead is resistant to corrosion by a wide variety of industrial chemicals of which the most important is sulphuric acid. Sulphuric acid is employed in almost every process industry. Consequently lead equipment is at least a possibility in

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almost every process industry. In general lead resists sulphuric acid quite well in concentrations up to 96% cold and 85% boiling. Its resistance results from the formation on its surface of a highly insoluble coating of lead sulphate. Therefore anything which tends to remove that protective coating tends to increase the rate of corrosion. Thus acid passing through lead pipes at high velocities or acid in lead reaction vessels that is greatly agitated, increases corrosion and shortens the life of the equipment. Likewise solids in suspension in the acid may abrade the coating and shorten the life of the lead. Lead equipment should therefore be designed to minimize velocities and agitation. This is often accomplished by using larger pipes, for example, to give equal volume at reduced flow rates.

These principals may be said to apply throughout lead's use as a corrosion resistant material and not just to its use with sulphuric acid. Lead is used commercially to handle, in addition to sulphuric acid, many other corrosives including phosphoric acid, chromic acid, hydrofluoric acid, aluminum, copper, ferric, ferrous and nickel sulphate and sodium chloride. I have here a paper which describes lead's performance in contact with some 75 chemical compounds, so I won't take time now to give you the details. Those who are interested may have copies of this paper. Suffice it to say that in general it is the formation of an insoluble lead salt, such as the sulphate, phosphate, chromate, and so on, on the surface of the lead which protects it against corrosion. On the other hand if a relatively soluble lead salt is formed, it does not protect the lead and corrosion may proceed rapidly. A good example is the rapid corrosion of lead by nitric acid, lead nitrate being soluble.

In designing lead chemical equipment its other properties, particularly its low creep strength, must be considered. Consequently lead is rarely used alone, but is more often a lining for steel, wood, concrete or some other structural material.

There are several methods of installing lead linings depending upon conditions. In shallow tanks and at normal temperatures loose linings are usually satisfactory. In these the lead is usually turned over the rim of the tank at the top and given no other support.

In deep tanks or at higher temperatures, a series of vertical supports are advisable. These usually consist of steel straps on 18 to 36 in. centers bolted through the lead to the supporting shell of the tank. These steel straps are in turn covered with strips of lead welded to the lead lining on each side.

For extremely high temperatures or wide temperature fluctuations, acid brick linings inside the lead linings are often used. These serve the dual purpose of helping to support the lead and insulating the lead against the high temperatures. They also protect against mechanical damage to the lead. Another method used for extreme conditions is to use lead homogeneously bonded to steel so that it is supported at all points. This also improves heat transfer if that is a factor.

In the design of piping for process industries the temperature and pressure has to be taken into account in calculating proper wall thickness. The usual formula is pressure equals two times the allowable fibre stress multiplied by the wall thickness divided by the inside diameter. The allowable fibre stress decreases as temperature increases. For chemical lead it is taken as 200 lb. per sq. in. at room temperature and drops to 80 lb. per sq. in. at about 300° F.

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Horizontal lead pipes are preferably supported continuously; vertical pipes every few feet. In pressures above 50 lb. steam pressure lead lined iron or lead covered copper should be used.

When particularly corrosive solutions are being handled in lead pipe it is always advisable to allow a little extra wall thickness to compensate for corrosion. The same is true of sheet lead linings in corrosion resistant equipment, lead weighing less than 8 lb. per sq. ft. rarely being used for that purpose, and often the lead is much heavier. Lead pipe is usually designated by its actual inside diameter and either its wall thickness or weight per foot. Sheet lead is usually designated by its thickness in fractions of an inch or its weight per square foot. Sheet lead weighs 1 lb. per sq. ft. for each 1/64 in. of thickness up to about 30-lb. lead, which is 1/2 in. thick.

The main points to consider in the use of lead for chemical equipment are, first, is it adequate from a corrosion resistant angle? More often than not, it is, but each case has to be considered independently. Where there are no case histories of similar installations as a guide, tests on samples under operating conditions are advisable if possible. Second, are operating conditions like agitation, high velocity or impurities in the solutions such as to accelerate the normal corrosion that might be expected? Third, high temperatures materially lower the strength of lead, requiring either special support or protection or the use of some other material often at a sacrifice in corrosion resistance. Fourth, lead is easily damaged mechanically, requiring protective liners if the lead is liable to be struck by hard articles or abraded by solids suspended in solutions.

Often lead is selected for use for various purposes because it is highly resistant to corrosion in the air. This is particularly true of industrial atmospheres where appreciable amounts of sulphur compounds are generally found. It is also resistant to salt atmospheres. Under such conditions the life of lead is virtually interminable. Witness lead roofs many hundreds of years old and the use of lead as flashings in ship construction.

Lead is likewise resistant to corrosion by practically all kinds of waters which leads to its extensive use for water pipes, including pipes to conduct salt water. A word of caution is advisable here. Lead pipe should not be employed to conduct drinking water that is very soft, not because it will be attacked to the extent of shortening its life, but because very soft water will dissolve more lead than is generally considered safe for human consumption. However, such waters will also dissolve copper or brass enough to cause green water and iron enough to cause red water and rust clogging. The answer is to treat the water to give it sufficient hardness so that it may be conducted safely in lead pipes, which is easily done.

Resistance to corrosion by most soils is another characteristic of lead that results in wide usage for sheathing on underground electrical and communications cable as well as pipes. In general soils are corrosive to lead in the following order — muck, cinders, sand and clay, muck being most corrosive.

One general warning should be given in connection with lead's corrosion resistance. It is rapidly attacked by free lime in new cement, concrete or mortar in the presence of moisture and oxygen. This action disappears when the cement becomes carbonated from the air in time. Therefore when using lead in construction, it should not be placed in contact with new cement unless it is coated with asphaltum which protects it until the cement is carbonated. A good example of this is the use of lead as safe pans under shower stall floors. It is standard practice to specify that such lead pans be coated with asphaltum.

Another outstanding characteristic of lead is its weight — the heaviest of the common metals. Lead weighs about 0.41 lbs. per cu. in. or about 707 lb. per cu. ft. and has a specific gravity of 11.37 therefore it must usually be excluded from consideration where lightness is required unless some other characteristic of lead makes its selection either imperative or desirable. In other words lead's weight is often a disadvantage, particularly on mobile equipment. For instance lead is not usually desired in aircraft. You wouldn't think of using lead in a plane if aluminum or magnesium or stainless steel would do the job. Yet lead storage batteries are used in planes because no other battery has the desired characteristics and you just have to put up with lead's weight to get them.

On the other hand there are instances where some other characteristics of lead make it possible actually to reduce the weight of equipment in which it is used despite lead's high specific gravity. Several examples could be cited. Lead coatings on certain aircraft equipment have sometimes reduced total weight since they need not be as thick as coatings of some lighter materials to get equal protection because of lead's high corrosion resistance. Lead X-ray room linings are lighter than concrete protective walls of equal insulating value because of lead's great ability to stop harmful rays. Lead soil pipe is lighter than cast iron soil pipe because it can be used with thinner walls. Lead roofing is lighter than slate or tile roofing because it is thinner. Lead counterbalances may reduce weight because the weight can be concentrated at the point where it has the most effect.

Although lead often must be excluded from consideration where light weight is important, there are many applications, such as weights and counterbalances, where lead must get consideration solely or largely because of its weight.

In such usage, the higher cost of lead is balanced against its ability to save space as compared with materials of lower specific gravity. Another consideration is the low melting point and easy casting of lead making it possible to fit lead weights into irregular and out-of-the-way spaces. In selecting lead for such work, its softness and low strength must sometimes be considered if the weight is subjected to mechanical abuse. In such instances, the lead weight is often enclosed in a cast iron or steel shell.

The high density of lead, 11.37 gm. per c.c., results in its selection for a number of purposes. Notable among these is X-ray protection, for the beta and gamma ray stopping power of a substance is proportional to density. Thus for

X-ray machines of ordinary power, or where space is the controlling factor, lead is usually employed as the protective medium. However, with high powered machines, the thicknesses of lead required are expensive, so that if space and weight are not too important, concrete, often in combination with lead, is generally employed. As a matter of fact, leading X-ray experts now recommend using lead in combination with concrete whenever concrete is employed because lead reduces scattered radiation.

The low strength of lead again must be taken into consideration in designing lead X-ray protection because the lead is not self-supporting and any supports fastened through the lead must be so covered as to prevent the escape of rays through the fastenings. In the case of ceilings of X-ray rooms, it is usually easier to lay the sheet lead on the floor above extending out sufficiently beyond the walls so that there is no direct path for the X-rays to follow between the top of the walls and the floor above.

Radium is also widely handled in lead protective devices for the same reasons that it is used for X-ray protection and atomic fission is naturally opening up an entirely new field about which not much can be said at the moment.

The thickness of lead to use in X-ray protection has been well worked out through experience and test and depends not only upon the power of the machine but also upon the distance from the target and time of exposure. These factors have all been considered in charts worked out by George Singer and George Lawrence of the U. S. Bureau of Standards, Washington and the National Research Council of Canada respectively. Their findings have been correlated, with the commercial thicknesses of lead, on a chart which we have prepared and which I will be glad to send to anyone requesting it.

Lead is one of the softest metals, its hardness on Moh's scale being 1.5, which is about the same as tin and less than any of the other common metals. The Brinell number, using a 1 centimeter ball for 30 seconds at 100 kilogram load, is 3.2 to 4.5 for common lead and 4.5 to 6.0 for chemical lead.

Softness is a characteristic of lead which accounts for its use in some instances or makes it necessary to take precautions in others. For example, the softness of lead is largely responsible for its employment as a calking material. This property makes it possible to calk lead to fill the joint completely. Softness accounts, at least in part, for other uses such as in bearing metals, gaskets, washers, lead headed nails and the like.

On the other hand, softness often makes it necessary to take certain precautions in the use of lead. In pipe lines, for example, high velocities may result in erosion. As I have already pointed out, this is sometimes eliminated by increasing the size of lines to reduce velocity or by increasing the wall thickness to compensate for erosion losses.

Likewise, the softness and tendency of lead to cold flow raises problems in connection with the use of lead gaskets and washers. The load which a lead gasket can carry without excessive flow is dependent upon several factors which include the thickness of the metal, the roughness or smoothness of the surfaces between which the gasket is placed and the temperature. In particular it should be remembered that the thinner the gasket can be made the greater will be the load it can take and the less will be its tendency to flow. Also, the smoother the surface between which it is placed and the higher the temperature the greater will be the tendency of the lead gasket to flow.

As an example of the malleability of lead we have its ability to be rolled to thin foil which is an important commercial application of lead. It is quite commonly rolled to thickness of 0.0006" and sometimes to even about half that thickness.

The characteristic flexibility of lead is an important contributing factor in many of its uses. Probably the most notable example is in the use of lead for cable sheathing which permits the cable to be coiled and bent as desired. The same may be said of lead pipe in many applications, particularly in water service pipe lines where it is possible, without making joints, to bend goosenecks integrally into the pipe and to bend the pipe around obstacles. Other uses which depend to a large extent on flexibility are the use of lead as a mold for rubber hose and lead collapsible tubes for paint colors, glue and other plastic or semi-plastic compounds. However, too much liberty should not be taken with lead's characteristic of flexibility as lead repeatedly flexed will eventually fail.

Lead has one of the lowest melting points of the common metals, the melting point being 327.4° C. or 621° F. This property of lead, and particularly of its alloys, results in its use for many purposes such as solder and fusible alloys. It contributes to many others such as castings and type metal by making the manufacture and use easy. It is often a disadvantage, as in chemical equipment, where lead must be confined to use in relatively low temperature operations. However, in the latter case, the disadvantage may be mitigated to some extent by properly supporting lead with other materials or actually bonding it to steel for support.

The fact that lead has both a low ultimate tensile strength and low creep strength must almost always be considered in applying lead commercially. Not always does this property make any difference, but more often it does. Even when strength is a factor, however, the low strength of lead does not necessarily preclude its use. Lead products can be designed so that lead will reinforce itself, or inserts or supports of other materials can be provided. Alloying with certain other metals, notably antimony, is a common method of strengthening lead. But in most uses of lead, adequate support should always be kept in mind. Thus horizontal lead pipes are usually continuously supported and vertical pipes at frequent intervals, as I have said. Sheet lead linings in deep tanks are supported by frequent lead covered steel straps.

The ultimate tensile strength of common lead is 1400 to 1700 lb. per sq. in. and of chemical lead is 2300 to 2800 lb. per sq. in. On the other hand, the ultimate tensile strength of a 7% antimony-lead alloy is in the neighborhood of 7200 lb. per sq. in. However, the strength of the antimonial lead alloys falls off more rapidly as temperature increases so that at high temperatures the antimonial lead alloys have little or no advantage over lead. Creep strength however is even more important than ultimate tensile strength. 200 lb. per sq. in. is usually considered a proper value to use for the creep strength of lead in most commercial applications at normal temperatures.

The fact that lead has good self-lubricating properties results in a number of commercial applications. As a coating on wire, it lubricates drawing dies, and as a coating on sheet metal it also acts as a drawing lubricant. Used in powder or wire form it lends proper lubricating properties to friction materials like brake linings, and as a powder it is employed in heavy duty lubricating greases and in pipe joint compounds.

The relatively high coefficient of thermal expansion of lead is another property which must be kept in mind in many of lead's uses. The linear coefficient of expansion is 0.0000293 per °C. The increase in volume from 20° C. to the liquid at the melting point is 6.1% and the shrinkage of casting as taken in practice as 7/64" to 5/16" per ft. The linear expansion is more than 50% greater than that of copper and more than twice that of iron. This high expansion rate naturally creates problems. For instance, in pipe lines subject to wide temperature variations provision must be made for free expansion. In roofing the lead has to be used in relatively small sheets which are loose locked and not soldered together so as to limit the expansion to any one sheet and prevent a cumulative effect.

On the other hand lead has relatively low electrical and heat conductivity. The relative electrical conductance of lead is 7.82 when copper is taken as 100. and the relative thermal conductivity is 8.2 when silver is taken as 100. The low electrical conductivity may sometimes have advantages. For instance, lead pipes buried in the ground are less apt to be electrolytically corroded by stray currents since the poor conducting lead is not apt to pick up these stray currents so readily as better conducting metals. The low heat conductivity, on the other hand, may sometimes be a disadvantage particularly in chemical equipment where lead is used in heat exchange coils. This is a minor disadvantage however as it merely affects the initial rate of heating and cooling and has little effect after the desired temperature has been reached.

I mentioned lead's ability to alloy with certain other metals in almost any proportion and its inability to alloy with others. Antimony and tin are the most commonly employed alloying metals. Antimony is generally employed to give greater hardness and strength as in storage battery plates, sheet, pipe and castings. Tin also increases hardness and strength but the lead-tin alloys are most commonly used for their melting characteristics as in solder. Tin in this case and in terne metal and other lead alloy coatings also imparts the ability to bond with metals like steel and copper, which lead alone possesses only in a small degree. Tin and antimony both also improve the casting qualities of lead. Bismuth is often alloyed with lead to obtain, usually with tin too, the extremely low melting alloys. Although lead does not alloy readily with copper, it is combined in rather high percentages with copper in certain bearing alloys, and is frequently used in smaller percentages in bronzes and free machining brasses. Likewise, though lead is difficult to alloy with steel, it is employed in fractional percentages in free machining steel. Calcium, magnesium and sodium in fractional percentages are sometimes alloyed with lead in special bearing alloys and cable sheathing. Cadmium additions to lead have been found helpful in coating copper wires with lead. In general, lead usually alloys quite readily with most of the white metals, and despite the greater difficulty of alloying with copper and steel, it is frequently used with those metals.

A more detailed discussion of these alloys would virtually constitute a subject in itself since the variety of compositions used is tremendous. The most common solder alloys are those containing 50% tin and 50% lead, and 40% tin and 60% lead. During the war when tin was so scarce it was necessary to reduce the tin content of solders considerably and solders containing 20 or 30% tin only were widely employed and in most cases successfully. However, in general there has been a return to the higher tin content solders because they are easier to handle particularly in hand soldering operations. In machine soldering operations, however, such as in the canning industry the lower tin content solders appear to have worked satisfactorily after adjusting production methods to the higher temperatures and wider plastic ranges that they handle. Some solders containing up to a couple percent silver, with a small percentage, or no tin, have been used. They have the advantage of additional strength but the disadvantage of fairly high soldering temperatures.

There is one relatively new field of application of lead on which I would like to spend a little time, which has to do with its alloying ability. That is the use of certain lead alloys for protective coatings on iron and steel. The scarcity of tin, zinc and cadmium for coating during the war led to a considerable amount of experimental work on lead as a protective coating. Attempts to use pure lead were not satisfactory because of lead's poor ability to wet and alloy with the steel base. It was found, however, that highly satisfactory coatings could be applied if the lead were alloyed with only relatively small amounts of tin or tin and antimony and as a result a considerable amount of lead alloy coated steel was used for such purposes as pole line hardware and radio chassis. Currently the most popular alloys being used, aside from the conventional terne plate which has been known for many years and which contains from 12 to 20% tin, are: lead plus 7% tin and lead plus 2-2-1/2% tin and 2-2-1/2% antimony with sometimes a fraction of a percent of silver. Several manufacturers are using these alloys to coat products such as roofing hardware, automobile gasoline tank spouts and for small articles. Several plants have been set up to do hot dip lead alloy coating on the jobbing basis for others.

One deterrent to the adoption of lead or lead alloy coatings in earlier years was the prevalence of pin holes in these coatings. However, work done during the war demonstrated that using the proper fluxes and alloy the pin holes could be minimized and that such pin holes as there were in the coating did not affect its life. While there may be some initial rusting of lead coated steel as a result of these pin holes it has been found that the pin holes are self-sealing and rusting does not proceed beyond the initial stage, the rusty appearance actually disappearing in time. In other words, lead coated steel that is exposed to the atmosphere or to salt spray tests looks better after a period of exposure than it does in the initial stages of exposure.

To get equal protection with lead alloy coatings as compared with some other kind of metallic coating, it is generally agreed that a lighter coating may be used and the coating has several other advantages. For instance, a lead coating provides an ideal base for paint without any special preparation other than to remove oil or grease from the surface. Lead coated steel articles may be readily soldered or welded. I personally look for continued expansion in the use of lead alloy coatings as the methods of application and their virtues become better known.