TEN COMMANDMENTS OF MATERIAL DETERIORATION

I. ASSUME WATER WILL GET IN AND MAKE PROVISIONS FOR GETTING IT OUT.

II. LEARN THE BAD POINTS OF A MATERIAL/PROCESS AS WELL AS THE GOOD POINTS.

III. DO NOT ASSUME MAINTENANCE IS THE REMEDY FOR BAD DESIGN.

IV. POSITION PC BOARDS VERTICALLY, NOT HORIZONTALLY.

V. DO NOT COMBINE DISSIMILAR METALS ESPECIALLY WHEN LARGE CATHODE/SMALL ANODE CONDITIONS ARE THE RESULT.

VI. DO NOT EXPOSE STRESSED MATERIALS TO SPECIFIC CORROSIVE ENVIRONMENTS.

VII. PROVIDE PROTECTION OF MATERIALS TO PREVENT GENERAL DETERIORATION.

VIII. USE ALLOYS AND THERMAL TREATMENTS TO PREVENT PITTING AND INTERGRANULAR ATTACK.

IX. KEEP MANUFACTURING/FINISHING PROCESSES UNDER CONTROL TO MAINTAIN MAXIMUM QUALITY.

X. DO NOT ASSUME AN ‘ENVIRONMENT’ – IT WILL ALWAYS BE WORSE.

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THE TEN COMMANDMENTS OF MATERIAL DETERIORATION

Today’s corrosion engineer is basically concerned with all types of material deterioration. In a broad sense, the corrosion engineer is concerned with preserving the designed function of a structure, piece of equipment or other items used in the military or commercial arena. The complexity involved in today’s designs, the proliferation of new materials, manufacturing technology and OSHA/EPA requirements, make the corrosion engineer’s job even more demanding.

Due to the lack of information in the area of long-term performance of today’s materials, the corrosion engineer must rely basically on his experience and common sense when addressing potential corrosion or material deterioration problems. These “Ten Commandments of Material Deterioration” will provide a practical rather than theoretical approach to maintaining the design function over the effective useful life of the equipment. These “commandments” apply to items currently being designed and the rework of items already in the field.

I. ASSUME WATER WILL GET INTO YOUR EQUIPMENT AND MAKE PROVISIONS FOR GETTING IT OUT.

Water gets into used and stored equipment via free water entry, condensation, “desiccant pump,” steam cleaners and pressure washers. Free water entry occurs during s shower or rainstorm, washing the equipment, coffee or beverage spillage, run-off of accumulated water or any number of other unexpected situations. Condensation occurs on the surface of materials when the temperature goes through the dew point. “Desiccant pump” occurs when a container with desiccant in it develops a leak. The desiccant absorbs moisture from the container and the outside air until it becomes saturated. Subsequent heating of the desiccant releases water to the inside of the container. Water in the confined space results in the container becoming a humidity cabinet.

One of the most effective means of getting water out is through the use of a drain hole. The guidelines for putting in a drain hole are obvious but not always adhered to, so they are reiterated here. (1) Put the hole in the lowest portion of the area to be drained, (2) the drain hole must be large enough for water to run out, (3) the drain hole must be large enough to allow debris to be removed with the water and (4) the drain hole must be large enough to allow a protective coating to be applied to the walls of the drain hole. In spite of their simplicity, the guidance housing casting for the Hawk missile failed all four of these criteria and the guidance provided by MIL-STD-721 in the past indicates more attention should be paid to these concepts. Breather systems can be used to eliminate the effects of condensation and “desiccant pump” problems. Also, follow the packaging center’s guidance and replace desiccant every 18 to 24 months or design accordingly. Remember, keeping water out eliminates the electrolyte required to support any corrosion cell.

II. LEARN THE BAD POINTS ABOUT A MATERIAL AS WELL AS THE GOOD POINTS – THEY MAY BE MORE IMPORTANT.

Let’s say you are looking for an electrical insulation material that has good high and low temperature characteristics, is not affected by weak acids and alkalis, is resistant to oils, alcohol and other hydrocarbons, is capable of being colored and is low cost. You would probably end up selecting a polyvinyl chloride (PVC) material. However, the decomposition of PVC materials by heat, light, age and atomic radiation is the biggest problem associated with their use. The effects of PVC deterioration include discoloration, embrittlement, stickiness and a general loss of properties. Mild heat, in the range of room temperature to 250^o F, causes a release of hydrogen chloride that reacts with moisture to form hydrochloric acid, a highly corrosive material. High heat due to a hot wire short or short circuit causes the formation of up to 75 potentially toxic materials including hydrogen chloride, chlorine monoxide, phosgene, and carbon monoxide. These two deficiencies (corrosivity and toxicity) are never cited in the data sheets involving PVC materials.

The short transverse stress corrosion cracking property of 7075-T6 aluminum is similar to an unknown physical characteristic that is not shown on most data sheets. While the longitudinal strength of 7075-T6 is in the 70,000 to 80,000 psi range, the strength level to which 7075-T6 can be loaded in the short transverse direction without encountering stress corrosion cracking is limited to a range of 6,000 to 9,000 psi. Thus, the orientation of the load is very critical when materials exhibit this “duality” in strength.

III. DO NOT ASSUME THAT MAINTENANCE IS THE PROPER REMEDY FOR BAD DESIGN.

Maintenance dollars are spent every day in an attempt to correct design deficiencies. As a result of poor design, maintenance is required in a short period of time. Unsealed faying surfaces or lap joints are an excellent example. When corrosion occurs, alkali is generated at the cathode and paint adhesion is lost and rust becomes evident. This reflects adversely on the maintenance man and soon he is involved in stripping and repainting again. The best example is probably the American automobile and the Army use of alkyd paints which have no alkali resistance.

Another maintenance concept is to replace components that have deteriorated with a component similar to the one that previously failed. As a result, we have become a nation of “parts changers” only to have the same problem surface again. Just as religion should not be thoughtless conformity to tradition, neither should our approach to material deterioration be based on the way we’ve done it in the past. To sum it up, there is no right way to do the wrong thing.

IV. POSITION PRINTED CIRCUIT BOARDS IN THE VERTICLE PLANE, NOT THE HORIZONTAL PLANE.

Printed circuit boards positioned in black boxes in the horizontal position are susceptible to dust, dirt, debris, moisture condensation and spillage accumulations. These accumulations constitute a corrosive atmosphere inside the black box resulting in circuit and component failures. Galvanic corrosion between dissimilar metal contacts, blossoming of soldering and plating residues, absorption of moisture by components that in turn causes a change of their input/output characteristics, short circuiting which occurs between traces and fungus growth are some of the situations encountered on supposedly “sealed” units. Vertical positioning minimizes accumulation of these contaminants and allows better convective cooling of the boards.

Situations to consider with sealed black boxes include (1) locating electrical feed-thru connectors on the side, (2) locating card connectors on the side or back, not the bottom, (3) using similar metals on the connectors and the printed circuit board contacts, (4) making sure the box can breathe if it is not hermetically sealed, and (5) do not use materials that emit corrosive vapors. Thinking of these situations during design and use will go a long way in improving the overall performance of printed circuit boards in black box assemblies.

V. DO NOT COMBINE DISSIMILAR METALS IN AN ASSEMBLY, ESPECIALLY IF LARGE CATHODE/SMALL ANODE CONDITIONS EXIST.

While galvanic (dissimilar metal) corrosion is probably the most familiar type of metallic deterioration, it is also the most neglected from the standpoint of anode/cathode area relationships. Graphite, for example, is cathodic to all materials except platinum and gold. When incorporated into dry film lubricants and used on magnesium, aluminum, steel, stainless steel or brass, graphite becomes the cathode and the other metals become the anode in the presence of an electrolyte. Graphite that is in direct contact with the metal causes severe pitting and can result in stress corrosion cracking in high strength materials. In this case, a small cathode/large anode situation exists, but the results can still be devastating. A solution to this problem by the Air Force resulted in substituting molybdenum disulfide for the graphite. However, molybdenum disulfide can also be corrosive forming molybdic and sulfuric acid during decomposition. Additions of antimony oxide and dibasic lead phosphite enhance the lubricity by acting as synergists in the presence of molybdenum disulfide. Thus, superior lubrication and corrosion resistance can be achieved with an INHIBITED molybdenum disulfide material. Copper plated steel “Bundy-weld” tubing used in many brake systems fail by severe pitting at voids in the copper plating. The pits can completely penetrate the steel resulting in a loss of brake fluid that can cause critical safety problems. The use of copper in contact with or plated on aluminum results in an even more potentially destructive situation. For example, copper flashing on roofs literally destroys aluminum gutters and down spouts. In the case of large cathode/small anode designs, while some people will doubt your sanity, by all means coat the cathode to reduce its effective size even though it doesn’t corrode.

VI. DO NOT EXPOSE HIGHLY STRESSED MATERIALS TO SPECIFIC CORROSIVE ENVIRONMENTS.

Specific corrodants (environments) for specific materials have been identified and reported. Typical examples like ammonia for brass and chlorides for stainless steel are reported continuously in corrosion periodicals. Likewise, hydrogen embrittlement during acid pickling, electrocleaning and electrodeposition or alkaline blackening of high strength steels represents a potential corrosive environment for these materials. It must be pointed out that many other materials are prone to failure in specific environments. Polycarbonate (Lexan) plastics, for example, are susceptible to stress cracking in the presence of oxygenated and chlorinated hydrocarbons (degreasing solvents). Many synthetic rubbers under stress are susceptible to cracking in ozone environments. Susceptibility can develop in inherently ozone resistant rubbers when reclaimed rubber or other filler materials are added during compounding. Fuel line hoses are an excellent example of this situation. Various coatings on rubber can cause localized (accelerated) ozone cracking. Paints and tire dressings should be avoided. The topical application of antiozonant materials (per MIL-D-50000) is the one procedure that results in increased performance of rubber items. This was at the Rock Island Arsenal in the 1956-1958 time frame.

VII. PROVIDE ADEQUATE PROTECTION OF MATERIALS TO PREVENT GENERAL DETERIORATION.

Various materials perform satisfactorily in numerous environments and do not require protective coatings. However, materials like steel and its alloys, aluminum alloys and magnesium must be protected to prevent general deterioration. Inorganic (sacrificial) coatings on steel or organic (paint) coatings on aluminum or magnesium are examples of protection required to prevent material deterioration.

The real problem today is the use of coatings that are hardly adequate. Alkyd paints continue to be used as primers on bridges in lieu of zinc-rich primers. The result is the reported poor condition of many bridges in the U.S., especially in my home state, Iowa. In a response to my suggestion, the state complained about the cost of using silicone/alkyd paints compared to the cost of lead-based alkyd paints. Zinc-rich paints have provided in excess of twenty years' protection of structures at Cape Kennedy and are in use on the Golden Gate Bridge in San Francisco. Epoxy primers and urethane topcoats are applied to aircraft, and commercial vans and trucks to provide maximum corrosion resistance and resistance to alkali formed at the cathode during the corrosion process thus maintaining paint continuity at faying surfaces and dissimilar metal assemblies.

VIII. PROVIDE THE NECESSARY ALLOYS AND THERMAL TREATMENTS TO PREVENT PITTING AND INTERGRANULAR ATTACK.

The use of stainless steel in rural environments provides adequate corrosion protection. However, the use of stainless steel is often associated with much more severe environments. An example of this is the use of stainless steel in the chemical process industry. Welded stainless reactor vessels and piping containing nitric and sulfuric acid may be susceptible to intergranular corrosion. Chromium, the main alloying ingredient providing the corrosion resistance, is depleted during welding by reaction with carbon. The area adjacent to the weld is then susceptible to accelerated intergranular attack. Titanium or columbium can be alloyed to prevent the formation of chromium carbides.

Also, low carbon stainless steel and various thermal treatments can be used to eliminate the problem. The use of stainless steel in aggressive environments like sea coastal areas may result in pitting corrosion. Chloride from the salt environment can cause the formation of small, localized anodes that can perforate stainless steel tubing. Debris settling on horizontally positioned stainless steel tubing at Cape Kennedy resulted in similar deterioration of stainless steel materials. Zinc-rich paint was applied at the Cape to provide cathodic protection. Also, the addition of molybdenum as an alloying ingredient to conventional stainless steels has been shown to improve their resistance to deterioration by pitting.

IX. KEEP MANUFACTURING/FINISHING PROCESSES UNDER CONTROL TO MAINTAIN MAXIMUM QUALITY.

Most manufacturing/finishing processes were initially designed to provide maximum quality. Specifications were then established to define how this quality was to be maintained. It soon became apparent that testing to insure maximum quality was not only time consuming and resulted in production delays, but also was very expensive. As a result, the practice of minimum testing was accepted to alleviate these problems. Today, just passing the minimum is being construed as best available technology. An example of this would be phosphate coating technology. When I first started working for the Army, the average heavy zinc phosphate coating with no supplemental finish would generally pass 20-24 hours in the five percent salt spray cabinet. The finishing process consisted of vapor degreasing, steel grit blasting and one-half hour immersion in the phosphating solution at 198^{o} F to 205^{o} F. Parts were rinsed in cold water and given a chromic acid final rinse. Today, acid and/or alkaline cleaning is used since it is more amenable to automated processing; lower processing temperatures are used due to energy considerations; and subsequent water rinses are warm to hot due to water conservation, disposal problems and overall production volumes. As a result, the two hour minimum salt spray requirement must often be waived to accept parts needed in the field. A high percentage of what is received by the depots must be rephosphated before it used in the rework operations. This represents a significant change in just twelve years. It appears that implications of the word “quality” means something different today than it did a few years ago.

X. DO NOT ASSUME AN ENVIRONMENT OR USE SITUATION – IT WILL ALWAYS BE WORSE.

In the design of equipment, certain functional requirements must be achieved. Knowing the type of equipment being designed, various operational environments are assumed in which the equipment must perform. When the design is conducted with consideration of the environment, long term reliability can be accomplished.

In most cases, however, testing or operational environments are often far removed from the environments the equipment sees in actual use. The Army performs various operational tests on trucks, missiles and communications equipment in various locations throughout the southwestern deserts. Use of this equipment in Southeast Asia resulted in less than desirable performance. During the monsoon season, the temperature went through the dew point 23 times in a 24 hour period. None of the equipment saw any "dry" environment, only varying degrees of wetness. Thus, the desert environment is hardly indicative of that real world environment. Sometime ago the president of a large automobile corporation was asked what his company was doing about corrosion problems being experienced by his vehicles in the Midwest. His response was that it wasn't his company's problem; it was something external to the car, it was the environment and he (the company) couldn't do anything about it. His answer reflected the company's inability to consider the effects of salted streets in the winter months in the design of the car. Shipping equipment in freighter or in railroad cars that were previously used to haul ammonium nitrate fertilizer is another example of an unassumed environment.

Problems in any one of these ten areas should be considered during design and corrected if detected during testing. In this way, the design and the materials used will result in manufactured equipment that will provide reliable performance for a long time. If this is not done, a lot of money will be spent in the field on equipment that has low reliability or is totally incapable of performing its intended functions.