Environmental, Health, and Safety Guidelines for Metal, Plastic, and Rubber Products Manufacturing

Introduction

The Environmental, Health, and Safety (EHS) Guidelines are technical reference documents with general and industry-specific examples of Good International Industry Practice (GIIP)[1]. When one or more members of the World Bank Group are involved in a project, these EHS Guidelines are applied as required by their respective policies and standards. These industry sector EHS guidelines are designed to be used together with the **General EHS Guidelines** document, which provides guidance to users on common EHS issues potentially applicable to all industry sectors. For complex projects, use of multiple industry-sector guidelines may be necessary. A complete list of industry-sector guidelines can be found at: www.ifc.org/ifcext/enviro.nsf/Content/EnvironmentalGuidelines

The EHS Guidelines contain the performance levels and measures that are generally considered to be achievable in new facilities by existing technology at reasonable costs. Application of the EHS Guidelines to existing facilities may involve the establishment of site-specific targets, with an appropriate timetable for achieving them.

The applicability of the EHS Guidelines should be tailored to the hazards and risks established for each project on the basis of the results of an environmental assessment in which site-specific variables, such as host country context, assimilative capacity of the environment, and other project factors, are taken into account. The applicability of specific technical recommendations should be based on the professional opinion of qualified and experienced persons.

When host country regulations differ from the levels and measures presented in the EHS Guidelines, projects are expected to achieve whichever is more stringent. If less stringent levels or measures than those provided in these EHS Guidelines are appropriate, in view of specific project circumstances, a full and detailed justification for any proposed alternatives is needed as part of the site-specific environmental assessment. This justification should demonstrate that the choice for any alternate performance levels is protective of human health and the environment.

Applicability

The EHS Guidelines for Metal, Plastic, and Rubber Products Manufacturing address material processing operations common to multiple industries engaged in the manufacture of metal, plastic, and rubber products. It does not include extraction or production of raw materials (metals, plastics, and rubber), metal casting, or synthesis of thermoplastic polymers or additives. Annex A contains a description of industry sector activities.

This document is organized according to the following sections:

[1] Defined as the exercise of professional skill, diligence, prudence and foresight that would be reasonably expected from skilled and experienced professionals engaged in the same type of undertaking under the same or similar circumstances globally. The circumstances that skilled and experienced professionals may find when evaluating the range of pollution prevention and control techniques available to a project may include, but are not limited to, varying levels of environmental degradation and environmental assimilative capacity as well as varying levels of financial and technical feasibility.

1.0 Industry-Specific Impacts and Management

The following section provides a summary of EHS issues associated with metal, plastic, and rubber products manufacturing activities, which occur during the operational phase, along with recommendations for their management. Recommendations for the management of EHS issues common to most large industrial facilities during the construction and decommissioning phases are provided in the **General EHS Guidelines**.

1.1 Environment

1.1.1 Metals

Environmental issues manufacturing of metal products manufacturing primarily include the following:

- Air emissions
- Wastewater and liquid wastes
- Solid waste

Air Emissions

Table 1 presents a list of the most common air emissions for typical metal manufacturing processes. Sintering may generate combustion by-products and greenhouse gases resulting from energy requirements. Inorganic and organic volatile compounds may be generated from oxides, dusts and lubricants (e.g. waxes or graphite) used in the charges before compaction. Handling of micro-sized metallic particles (approximately 1 µm of diameter) may generate metallic dust. Emissions from casting are covered in the **EHS Guidelines for Foundries.**

Air emissions from forming processes may include solvents and cooling / lubricant solutions used in the equipment, or vapors generated from quenching (e.g. after hot forming or after annealing). Oil and grease mists and vapors may derive from use of automated mechanical tools.

Table 1 – Air Emissions from metal products manufacturing

Process	Air Emission
Sintering	Fugitive dust, particulates, carbon monoxide, sulfur dioxide, nitrogen oxides, chloride and fluoride compounds, VOCs (e.g. polystyrene vapors, hydrocarbons), metallic fumes (volatilized metal and metal oxides)
Metal Shaping	
Metal cutting, grinding and / or forming (including forging, wire drawing, pressing, stamping, among others)	Fume and cutting fluid mists [in processes where cutting / lubricating / cooling fluids are heated (e.g. wire drawing)]. In case of hot works or high wearing effects, some lubricants may decompose and produce VOCs
Thermal Treatments	
Quenching, annealing and other general treatments	Mist, VOC / solvents, fumes, particulates (e.g. chromium or nickel oxidized vapors)
Surface Preparation	
Abrasive treatments (e.g. shot, sand blasting)	Dust, comprising abrasive particles, metals and metal oxides.
Solvent degreasing and emulsion, alkaline, and acid cleaning	Solvents (associated with solvent degreasing and emulsion cleaning only), VOC, fumes, acid or alkaline vapors containing ammonia, ammonium chloride
Welding	Particulate, chromium (VI) and nickel oxidized vapors, ozone, vapors (as metals or as oxides) of lead, cadmium, zinc, tin, iron, molybdenum, manganese, cobalt, vanadium, silica and silicates, fluorides, nitrogen oxides, carbon monoxide, carbon dioxide, phosgene (carbonyl chloride), phosphine
Surface Finishing	
Anodizing, chemical conversion coating, electroplating	Metal-ion-bearing mists and acid mists, hydrochloric acid, sulfuric acid, ammonia, ammonium chloride, zinc oxide, particulate matter, lead, copper, chlorine
Painting	Solvents
Other metal finishing techniques (Including polishing, hot dip coating, and etching)	Metal fumes and acid fumes, zinc oxide (from water quench), VOC, nitrogen oxides, particulate matter, sulfur oxide (from heating the zinc bath)

Thermal treatments during annealing and quenching generate air emissions from furnaces (e.g. furnace fuel combustion by-products, and emissions resulting from burning of oils and greases present on the surface of metals) and quenching bath emissions (e.g. water mixed with chemical additives or synthetic oils) such as vapors or mists.

During welding processes, air emissions are linked to the base material to be welded and to the selected welding method. In particular, emissions may be generated from the molten pool, the shielding gases, the reaction of the external part of cored electrodes with the atmosphere, and by the burning of oils / greases present on raw product. Special attention should be paid to the emissions arising from the coatings that eventually cover the base metals.

Air emissions from metal surface cleaning are related to the evaporation of chemicals from degreasing, cleaning, and rinsing. Particulate emissions may be generated by sand blasting and dry surface grinding. These emissions may include metallic particulates and metallic oxides.

Electrochemical surface treatments produce air emissions, mists, and gas bubbles arising from heated fluids which may contain metals or other substances present in the bath. During painting, atmospheric emissions consist primarily of the organic solvents used as carriers for the paint. Emissions also result from paint storage, mixing, application, and drying.

Volatile Organic Compounds (VOC)

Recommended VOC emissions management strategies include:

- Installation of refrigerator coils (or additional coils) above the degreaser vapor zone;
- Application of an air flow over the top of the degreaser that should not typically exceed 40 m / minute;
- Rotation of parts before removal from the vapor degreaser, including:
  - Installation of thermostatic heating controls on solvent reservoirs and tanks
  - Installation of in-line filters to prevent particulate build-up
  - Use of solvent recovery to reduce emissions of VOC from curing ovens
  - Use of activated carbons to recover solvent vapors
- In order to reduce emissions during welding and coating, metal surfaces should be carefully cleaned;
- Coatings should be removed from the base metal before welding preferably using mechanical cleaning (for example blasting with CO_2-pellets) instead of solvents.

Dust

Recommended dust emissions management strategies include:

- Installation of in-line aspirators with filters or scrubbers. Electrostatic precipitators (ESP) may also be employed;
- Where possible, maintaining wetness on the metal surface in order to prevent or minimize dust production.

Acid / Metals Content in Mists and Fumes

Recommended management strategies for acid / metal content in mist and fume emissions include:

- Use of fume suppressants as additives to electroplating baths to reduce air emissions of electroplated metals (e.g. chromium);
- Installation of in-line aspirators with filters to eliminate acid compounds.
- For metals or metal oxides abatement, installation of filters capable of handling complex metals;
- Welding fumes (a mixture of metals, oxides, and smoke from burning off oil) should be controlled by removing coatings from base metals. Chlorinated hydrocarbon

solvents should not be used for this purpose, to prevent the risk of phosgene creation.

Wastewater and Liquid Wastes

Typical sources of wastewater discharges from metal product manufacturing of include water-based cleaning and rinsing streams; cooling water; alternative cleaners; wastewater generated from cutting, blasting, deburring and mass finishing activities; and water-based metalworking fluid operations. Table 2 lists process wastewaters generated from metal products manufacturing processes.

Table 2 - Liquid Wastes from Metals Product Manufacturing	
Process	**Process Wastewater**
Sintering	Metal oxides, phenols, grease, spilled oils, suspended and dissolved solids and metals (metal-bearing sludges)
Metal Shaping	
Metal cutting, grinding, and / or forming	Waste machining fluids (e.g. ethylene glycol , oil-based fluids; oil-water-emulsions, synthetic emulsions) and acid (e.g. hydrochloric, sulfuric, nitric), alkaline, and solvent wastes
Surface Preparation	
Solvent degreasing and emulsion, alkaline, and acid cleaning	Surfactants, emulsifiers, detergents, terpenes, alkaline or acid wastes, metal salts, dissolved base materials
Welding	Contaminated cooling bath used to quench after welding
Surface Finishing	
Anodizing, chemical conversion coating, electroplating	Acid / alkaline wastes, metals, metal salts, zinc, chromium (VI), cyanide
Painting	Solvent wastes, spills, and still bottom
Other metal finishing techniques (including polishing, hot dip coating, and etching)	Metal (e. g. zinc, chromium [VI]) and acid or alkaline wastes

Thermal treatments and hot work, including welding, may be followed by quenching in a liquid media. Quenching is also important in casting and sintering. Further details on casting are included in the **EHS Guidelines for Foundries.** The quenching bath is usually water or water-based and may contain chemical additives (e.g. organic solvents, phenols, oil and grease). Spent quenching baths may include residuals of additives and their secondary products, suspended solids, and metallic dross (e.g. oxides formed during solidification).

Wet scrubbers used for fumes control may generate wastewater that may contain metals and phenols, and is typically highly alkaline or acidic and should be neutralized before being discharged. Thermal pollution from discharge of non-contact cooling water should be avoided by use of recirculating cooling systems, for example using cooling towers.

Fluids resulting from metal cutting, grinding and forming typically become contaminated due to extended use and reuse. Metal machining fluids may be petroleum-based, oil-water emulsions, and synthetic emulsions. Fluids may decompose into their components due to use and reuse, and spent fluids can contain many different compounds, including some derived from the combination of metals and metal oxides with the degraded fluid constituents. Spent fluids may contain high amounts of metals (e.g. iron, aluminum, and copper), acids and alkalis (e.g. hydrochloric, sulfuric, and nitric acids), and organics (e.g. ethylene glycol, acetic aldehyde and formaldehyde, straight oils, soluble oils, semi-synthetic fluids, synthetic fluids, and solvent wastes).

Surface preparation may result in wastewaters (primarily from rinsing) from cleaning activities. Aqueous cleaners are water-based chemicals that can be categorized into two major groups, namely acidic and alkaline-based products. Both types of aqueous cleaners contain surfactants (surface-active agents), emulsifiers (for oil removal), detergents, and terpenes (in case of semi-aqueous cleaners). Aqueous wastes from alkaline and acid cleaning, which do not contain solvents, may be treated on-site.

Hot dip coating techniques (e.g. galvanizing) use water for rinsing following pre-cleaning and for quenching after coating. Hot dip coatings generate solid waste, an oxide dross that is periodically skimmed off the heated tank. These operations may generate metal-bearing wastewaters. Etching solutions are comprised of strong acids (e.g. nitric acid), or bases. Salts (e.g. ammonium persulfate, ferric chloride) are used to produce etching solutions. Spent etching solutions may contain metals and acids. Metal plating and related waste account for the largest volumes of metal-bearing wastes (e.g. cadmium, chromium, copper, lead, and nickel) and cyanide-bearing wastes.

Painting operations generate solvent-bearing wastes and the direct release of solvents (including benzene, methyl-ethyl-ketone, methyl-isobutyl-ketone, toluene, and xylenes). Painting operations may also generate wastewater from disposal of materials used to contain paint and over-spray, and from excess and / or expired paints.

Anodizing operations may produce process wastewaters which contain nickel acetate and non-nickel sealers. Other potential pollutants include complexers and metals, which may be combined with other metal finishing wastewaters and treated on-site by conventional hydroxide precipitation. Wastewaters containing chromium (e.g. wastewater from chemical conversion coating) should be pretreated to reduce hexavalent chromium to its trivalent state. The conventional treatment process generates a sludge that is usually sent off-site for metals reclamation and / or disposal.

Effluents usually contain significant pollutants, and can be differentiated into separate streams, including wastewaters potentially impacted by oils and solvents; surface treatment / finishing wastewaters; and metal containing wastewaters. Relevant pollution prevention and control measures include the following.

<u>Oil-based Effluents:</u>

- Effluent separation from wastewater, and special disposal if recycling is not possible;
- standardization of use of oil types, and efficient scheduling of processes that require use of varying oil types;
- Extend the life of cooling liquid through use of centrifuges, introduction of periodical analyses, use of biocides and ultrafiltration, and removal of oils by disk or belt skimmers. Use appropriate housekeeping techniques to prevent cutting oils from being contaminated with solvents;
- Oil quench baths should be recycled by filtering out metals;
- Metal-working fluids should be recovered using collection (or drip) pans under machinery;
- In cold forming or other processes where oil is used, automatic oilers should be used to reduce grease accumulation. A stamping lubricant suitable for conditions leading up to thermal treatment processes should be considered.

<u>Solvent and Water-based Effluents:</u>

- Solvents should be carefully managed to prevent spills and fugitive emissions. Guidance on storage and handling of solvents is provided in the **General EHS Guidelines;**
- Less hazardous degreasing agents (e.g. petroleum solvents, vegetable cleaning agents, VCA, supercritical CO_2 or alkali washes) should be considered, in addition to the use of countercurrent solvent cleaning (two-stage: first cleaning with dirty solvent, followed by fresh solvent); Aqueous non-VOC-containing alkali washes should be used for metal cleaning whenever possible. Some of these can be regenerated by microfiltration;
- Spent degreasing solvents should be recycled on site, reusing batch stills and waste solvents;

- Cold cleaning with recycled mineral spirits should be implemented before final vapor degreasing;
- Acids in wastewaters should be recovered through evaporation;
- Reduce rinse contamination via drag-out by optimization of part operation, using surfactants and other wetting agents;
- Use mechanical cleaning techniques instead of chemicals where possible (e.g. a vibrating abrasion apparatus for brass rather than acid pickling; mechanical scraping instead of acid solution to remove oxides of titanium; and rotating brush machines with pumice to clean copper sheets);
- Concentrations of dissolved metal ions should be controlled and reduced (e.g. molybdenum concentration reduction through reverse osmosis / precipitation systems; use of non-chromate solutions for alkaline etch cleaning of wrought aluminum; use of sulfuric acid / hydrogen peroxide dip instead of cyanide and chromic acid dip for copper-bright dipping process);
- Acid or alkaline pickling solutions should be replaced, if possible, with alternative cleaning agents (e.g. use of caustic wire cleaner with biodegradable detergent and use of linear alcohols instead of sulfuric acid to pickle copper wire, provided that adequate safety and fire prevention is implemented);
- Flow restrictors / control meters should be installed and a foot pump (or photosensor for automatic lines) should be used to activate rinse;
- Process wastewaters should be treated and recycled, using ion exchange, reverse osmosis, electrolysis, and electrodialysis with ion exchange.

<u>Surface Treatment / Finishing Wastewaters:</u>

- Strong complexing agents like EDTA and toxic surfactants like NPE and PFOS should be substituted by less hazardous alternatives;
- Anodizing and alkaline silking baths should be regenerated by recuperation of metallic (e.g. aluminum) salts through use of hydrolysis of sodium aluminate;
- Limit stocks of finishing material with short shelf lives;
- Painting jobs (light to dark) and the selection of spraying techniques should minimize wastewater production (e.g. use of a spray gun for particular applications, use of an electrostatic finishing system instead of conventional air spray);
- Avoid and substitute the use of chlorinated solvents (including carbon tetrachloride, methylene chloride, 1,1,1-trichloroethane, and perchloroethylene) with non-toxic or less toxic solvents as cleaning agents;
- Chromic acid and trisodium phosphate should be substituted by less toxic and non fuming cleaners (e.g. sulfuric acid and hydrogen peroxide), and cyanide cleaners substituted by ammonia;
- Less toxic bath components should be used (e.g. zinc in place of cadmium in alkaline / saline solutions; nitric or hydrochloric acids in place of cyanide in certain plating baths; zinc chloride in place of zinc cyanide);
- Drain boards, drip guards, drip bars, and dedicated dragout tanks should be installed, after process baths.

<u>Metals in Wastewater:</u>

- The management of water consumption is crucial, as it also reduces the usage of raw materials and their loss to the environment. Good process control and drag-out reduction are key factors for reducing the consumption of hazardous raw materials;

- Wastewaters with recoverable metals should be separated from other wastewater streams. Metals should be recovered from solution (e.g. using electrolytic cells or hydroxide precipitation);
- Used metal pickling baths should be sent to a continuous electrolysis process for regeneration and metal recovery;
- Metals from bright dipping solutions should be recovered using suitable processes (e.g. ion exchange system for copper, or segregating phosphates from treatment of aluminum based alloys);
- Solutions containing cyanide salts (e.g. for hardening processes) should be replaced with solutions using a fluidized bath of nitrogen and corundum;
- Hexavalent chromium should be substituted for plating, if this is not possible closed loops and covered vats should serve to minimize emissions.

Process Wastewater Treatment

Since general manufacturing operations, including metals, plastics and rubber products use a myriad of raw materials, chemicals and processes, wastewater treatment may require the use of unit operations specific to the manufacturing process in use.

Techniques for treating industrial process wastewater in this sector include source segregation and pretreatment of concentrated wastewater streams. Typical wastewater treatment steps include: grease traps, skimmers, dissolved air floatation or oil water separators for separation of oils and floatable solids; filtration for separation of filterable solids; flow and load equalization; sedimentation for suspended solids reduction using clarifiers; biological treatment, typically aerobic treatment, for reduction of soluble organic matter (BOD); biological nutrient removal for reduction in nitrogen and phosphorus; chlorination of effluent when disinfection is required; dewatering and disposal of residuals in designated hazardous waste landfills. Additional engineering controls may be required for (i) containment and treatment of volatile organics stripped from various unit operations in the wastewater treatment system, (ii)advanced metals removal using membrane filtration or other physical/chemical treatment technologies, (iii) removal of recalcitrant organics using activated carbon or advanced chemical oxidation, (iii) residual color removal using adsorption or chemical oxidation, (iv) reduction in effluent toxicity using appropriate technology (such as reverse osmosis, ion exchange, activated carbon, etc.), (v) reduction in TDS in the effluent using reverse osmosis or evaporation, and (vi) containment and neutralization of nuisance odors.

Management of industrial wastewater and examples of treatment approaches are discussed in the **General EHS Guidelines**. Through use of these technologies and good practice techniques for wastewater management, facilities should meet the Guideline Values for wastewater discharge as indicated in the relevant table of Section 2 of this industry sector document.

Other Wastewater Streams & Water Consumption

Guidance on the management of non-contaminated wastewater from utility operations, non-contaminated stormwater, and sanitary sewage is provided in the **General EHS Guidelines**. Contaminated streams (e.g. stormwater from exposed solid waste areas such as metal cuttings) should be routed to the treatment system for industrial process wastewater. Recommendations to reduce water consumption, especially where it may be a limited natural resource, are provided in the **General EHS Guidelines**.

Solid Waste

Metal manufacturing and related operations (e.g. wastewater treatments or fume reduction) may generate solid wastes. Table

3 lists the main solid wastes from metals product manufacturing as a function of their source.

Sintering produces a limited amount of solid wastes, mainly linked to raw material storage and handling (e.g. particulate, powders, and soil contamination from oil spills). During thermal treatments (e.g. annealing) oxide scales are formed. When quench or cooling baths are cleaned out, metal-bearing sludges may also be generated.

Metal forming produces a large quantity of metal chips (scrap metal), metal-bearing cutting fluid sludges, and solvent still-bottom wastes. Scrap metal consists mainly of metal removed from the intermediate piece (e.g. steel), and may be combined with small amounts of metalworking fluids (e.g. cooling or lubricant liquids) used prior to and during the metal shaping operation that generates the scrap. This type of scrap is typically reintroduced into the process as a feedstock. Welding slags, dusts and powders may contain various metal oxides depending on the base metals and their coatings.

Table 3 – Solid Waste from Metal Products Manufacturing

Process	Solid Waste
Sintering	Particulate, powders from
Metal Shaping	
Metal cutting, grinding and / or forming	Metal particles (e.g. iron filings, and chips or swarf arising from machining operations) metal-bearing machining fluid sludges, and solvent still-bottom wastes
Surface Preparation	
Solvent degreasing and emulsion, alkaline, and acid cleaning	Process sludge(s)
Welding (including multipass technique)	Metal oxides (e.g. oxides of Ti, Al, Fe, Ni, Cr, Cu, Zn or Sn) and slag drops
Surface Finishing	
Anodizing, chemical conversion coating, electroplating	Metal sludge(s), base metal and reactive compounds
Painting	Still bottoms, sludge(s, dried), paint, and metals
Other metal finishing techniques (Including polishing, hot dip coating, and etching)	Polishing sludge(s), metal (e.g. Zinc, Chromium) dross, etching sludges, oxide dross, metal sludge(s)

Surface preparation activities result in the generation of solid wastes (e.g. wastewater treatment sludges, still bottoms, cleaning tank residues, machining fluid residues). Anodizing, chemical conversion coating, electroplating, and painting may generate a number of spent solutions and wastewater whose treatment may result in the production of sludges, base metals, metal oxides, and several types of reactive compounds. Polishing, hot deep coating, etching and other metal finishing techniques generate the same wastes as anodizing, but with the addition of polishing sludges, hot dip tank dross, and etching sludges.

Pollution prevention and control measures include:

- Separating metal dust or scrap by type to promote recovery and recycling;
- Reducing and treating slags from welding, forging, machining, and mechanical finishing, which may contain metal ions;
- Proper management of metals removed from wastewaters for recovery or disposal;
- disposal of sludge from surface finishing processes (e.g. galvanizing, painting, hot dip).
- If reuse or recycling is not possible, the waste should be disposed of according to industrial waste management recommendations in the General EHS Guidelines.

1.1.2 Plastics and Rubbers

Environmental issues of concern arising from the manufacturing of plastic and rubber products primarily include the following:

- Air emissions
- Wastewater
- Solid waste

Operational activities that may generate adverse environmental impacts include granulation, compounding / resin formulation, shaping, and finishing. As plastic and rubber manufacturing processes differ mainly in the operations related to compounding / formulation and shaping, they are presented separately as part of these Guidelines. In recognition of the similarity of operations involving granulation and finishing during the manufacturing of thermoplastics and thermosetting polymers and rubbers, these issues are discussed together as part of these Guidelines.

Air Emissions

Plastics

Air emissions may contain particulate matter and volatile organic compounds (VOC). Particulate matter may be released during handling of dry additives and granulation of polymers. In addition, heating of thermoplastics during compounding and forming may result in formation and release of fine aerosols.

Recommended pollution prevention and control techniques for emission of particulate matter include:

- Optimize processing conditions for handling and mixing of dry additives, temperature, and polymer granulation;
- Filter air exhaust from material handling and granulation areas using a cyclone and / or baghouse;
- Capture and control fugitive emissions from production devices, typically through a primary cyclone and secondary baghouse or electrostatic precipitator.

VOC, including low-molecular weight additives and solvents, may be released during compounding and forming operations, especially when heated. During shaping operations for non-reactive plastics, the base polymers are stable well beyond the required processing temperatures with few exceptions. During shaping, however, water vapor, low boiling point additives, and monomer trapped in the polymer may be released, in particular at the hottest part in the processing line. Table 4 provides examples of commonly processed plastics and some of the constituents detected in fume when plastics are processed, or heated, above their recommended upper process temperature. Unlike other thermoplastic processes, manufacturing of expandable polystyrene (EPS) products requires that the raw materials be pre-conditioned prior to the final "tooled" molding process. In the conversion process, a small quantity of low boiling point liquid, usually a pentane isomer mixture (typically 3 to 8 percent by weight), is used as a blowing agent[2].

Table 4 – Potential Released Substances at High Processing Temperatures

Plastic	Examples of detected constituents
PVC–Polyvinyl chloride	Hydrogen chloride, Vinyl Chloride monomer
ABS – Acrylonitrile-Butadiene-Styrene copolymer	Styrene, phenol, butadiene
PP - Polypropylene	Aldehydes, Butane, other alkanes, alkenes
POM - Acetals	Formaldehyde
LDPE, MDPE, HDPE Polyethylene (low, medium and high density)	Aldehydes, Butane, other alkanes, alkenes
PS - Polystyrene	Styrene, aldehydes
PET - Polyethylene terephthalate	Formaldehyde, methoxy benzene, benzaldehyde and many different VOC

[2] CFCs have been used extensively in these processes, however they should not be used as part of current good industry practice due to the impact of fluorocarbons on the greenhouse effect and depletion of the ozone layer.

Recommended pollution prevention and control systems for VOC emissions include the following:

- Use of enclosed storage for all solvent and cleaning fluids, and for all low boiling point reagents;
- Installation of ventilation control systems, especially at the points of highest processing temperatures along the production line;
- Installation of local exhaust extraction systems and activated carbon adsorbers;
- Installation of recuperative / regenerative thermal oxidizers, catalytic / regenerative catalytic oxidizers, condensers or biofilters;
- Development and implementation of a Solvent Management Plan.

Rubbers

Fugitive emissions of additive chemicals may be released from the compounding area. As additives are pre-weighed, there is potential for significant fugitive dust emissions from chemicals kept in open storage. Fugitive emissions may also be produced as the chemicals are loaded into the mixer. Particulate emissions may be generated by surface grinding activities.

Recommended pollution prevention and control techniques for dust / particulate matter emission include the following:

- Use of chemicals in small, pre-weighed, sealed bags for direct addition to the mixer to limit dust generation;
- Emissions from the internal mixers should be controlled using bag filters. Exhausts from the collection hoods should be conveyed to the bag filters to control particulate and possibly particle-bound semivolatiles[3], ammonia, and metals (e.g. zinc, nickel, selenium, lead, cadmium, antimony compounds, and titanium dioxide).
- Dust and fine rubber particles, generated by surface grinding, should be controlled by a primary cyclone and a secondary bag filter or two-stage electrostatic precipitator.

Emissions of VOC and hazardous air pollutants may be generated. Solvents are used in various capacities during the rubber product manufacturing process. Recommended pollution prevention and control techniques for VOC emission include the following:

- Solvents should be carefully managed to prevent spills and fugitive emissions. Guidance on storage and handling of solvents, and other hazardous materials, is provided in the **General EHS Guidelines**;
- Solvent use should be minimized and water, silicon, and non-solvent-based release compounds should be used where possible.

Emission abatement equipment may be necessary in the event of significant emissions of VOCs. If extensive vulcanization is necessary to impart the desired properties to the rubber, emissions associated with rubber curing may contain sulfur dioxide (SO_2). Control of these emissions which may be controlled through use of scrubbers.

Wastewater

Effluents may contain solvents, oils, water-soluble and insoluble organic compounds released in the contact, processing and cleaning water, and solid particles with dimensions from submicron to several millimeters.

Plastics

Process wastewater used in the plastic molding and forming processes can be subdivided into three main categories: (1) cooling (or heating) water for plastics production; (2) surface cleaning and wash water used both for plastics product surface

[3] Ethylene thiourea, diethanolamine, hydroquinone, phenols, alpha naphthylamine, p-phenylenediamine, benzoyl peroxide, dibutyl phthalate, dioctyl phthalate, and bis(2-ethylhexyl) adipate.

cleaning and equipment washing; and (3) finishing operation water to remove waste plastic material or to lubricate the product.

Cooling (and heating) water may be a source of thermal pollution if discharged. Toxic pollutants potentially detectable in process wastewater discharged by contact cooling and heating processes include phthalates (e.g. bis[2-ethylhexyl] phthalate [DEHP]).

Cleaning water may be characterized by significant levels of biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD), total suspended solids (TSS), total organic carbon (TOC), oil and grease, total phenols, and zinc. Finishing water may contain significant levels of TSS and water soluble additives (e.g. phthalates).

Recommended pollution prevention options for contact, cleaning, and finishing wastewaters include the following:

- Adoption of good housekeeping practices;
- For contact water and finishing water, installation of activated carbon process to remove soluble organics, including phthalates (particularly important in manufacturing of plasticized PVC);
- Biodegradable plasticizers should be used where possible;
- For cleaning and finishing water, recycling process water through sedimentation / settling units and removal of the suspended solids, oils and grease.

Cooling water use may result in high rates of water consumption, as well as the potential release of high temperature water, residues of biocides, and residues of other cooling system anti-fouling agents. Recommended cooling water management strategies are discussed in the **General EHS Guidelines.**

Rubbers

Wastewater may be generated from cooling, heating, vulcanizing, and cleaning operations. Suspended solids, and oil and grease are potential contaminants of concern, in addition to trace metals (e.g. zinc). Wastewater originates from many production processes (e.g. cleaning of fresh latex receiving ponds, centrifuges, among others). Effluents arising from dipped latex rubber products may be impacted by additives which are employed to properly process the rubber. Odor may be generated by inadequate wastewater management.

Recommended treatments include solids settling, pH adjustment, or oil removal systems as needed. Wastewater should be trapped in a rubber trap, to let rubber float to the top for recycling / reuse. Wastewater should then be conveyed to treatment plant. Closed-loop water cooling or heating systems should also be considered.

Solid Wastes

Significant quantities of solid waste are not typically generated in plastics and rubber manufacturing as scrap materials resulting from shaping and finishing operations can be recycled. Scorched rubber from mixing, milling, calendering, and extruding may be a significant solid waste source, in addition to waste rubber produced during rubber molding operations, particulate matter from bag filters in compounding areas, Banburys, and grinders, and ..

In addition to the guidance for management and disposal of industrial waste described in the **General EHS Guidelines**, the following are recommended management measures:

- Waste streams should be properly segregated (e.g. uncured rubber, cured rubber, and off-specification products);

- Uncured rubber, as well as slightly cured waste rubber, should be recycled to Banbury mixers;
- Cured and off-specification rubber waste should be either recycled at the facility or reused (through shredding) to make other products;
- Scrap from thermoplastic polymers should be reground and mixed with virgin materials;
- If reuse or recycling is not possible, the waste rubber (including scrap polymer parts that have been excessively heated) should be disposed of according to industrial waste management recommendations in the **General EHS Guidelines**.

1.2 Occupational Health and Safety

Occupational health and safety impacts during the construction of manufacturing plants for metallic, plastic and rubber products are common to those of most industrial facilities and their prevention and control is discussed in the **General EHS Guidelines**.

1.2.1 Metals

Occupational health and safety issues associated with metal product manufacturing primarily include the following:

- Chemical hazards
- Physical hazards
- Noise
- Radiation

Chemical Hazards

Workers may be exposed to inhalation and dermal contact hazards associated with chemicals used during metal product manufacturing, in particular during sintering, surface preparation, and finishing. Inhalation hazards may include fumes containing metals, metal oxides, organic and inorganic compounds, particulates, dust, and VOC. Dermal hazards may include contact with allergenic elements (e.g. chromium, nickel, lead, and beryllium). Chemical hazards should be managed based on the results of a job safety analysis and industrial hygiene survey and according to the occupational health and safety guidance provided in the **General EHS Guidelines**. Protection measures include worker training, work permit systems, and use of personal protective equipment (PPE). Specific prevention and control of occupational exposure to air emissions during metal product manufacturing include:

- Use of automated equipment. If an operator is needed, a closed cabin with air ventilation should be provided;
- Use of moveable hoods and masks during operations where the worker is exposed to potentially harmful emissions (e.g. welding);
- Use of air emissions extraction and recycling systems (e.g. during quenching, and surface finishing).

Physical Hazards

Physical hazards include exposure to metal cutting and forming tools and machinery drives which slice nicely through hands and flying metallic particles (e.g. metal chips arising from machining operations) which can injure eyes. , Heat cold and ergonomic stress, may result in bodily injury. Heavy items, or bins containing many such items are often moved by crane or fork-lift truck. Guidance on the management of physical hazards is provided in the **General EHS Guidelines**.

Noise

Metal products manufacturing operations are inherently noisy due to the large amount of mechanical equipment and activities. Guidance for noise management is provided in the **General EHS Guidelines**.

Radiation

Operators may be exposed to radiation during welding. Certain welding techniques (including all the arc, plasma, laser and electron beam welding methods) use significant energy and generate radiation that may be dangerous for the operator. Automation should be used, when possible, or adequate personal protection equipment to shield the operator against radiation. Another source of radiation involves X-ray stations for continuous monitoring of product quality. Recommended management of ionizing radiation hazards are described in the **General EHS Guidelines**.

1.2.2 Plastics and Rubber

Occupational health and safety issues associated with plastic and rubber products manufacturing primarily include the following:

- Physical hazards
- Chemical hazards

Physical Hazards

Many physical hazards in plastic and rubber processing are similar to those found in the metal manufacturing industries and should be managed in the manner described in the **General EHS Guidelines.**

However some physical hazards specific to this industry may be managed as described below:

- Use of electrical switch off systems and mechanical brakes to stop blade rotation when workers are in close proximity to the revolving parts / blades;
- Installation of emergency stop switches within reach of operating stations;
- Use of guards to prevent access to material feed openings and discharge points near rotors, cutters, blades and screws / rams. To facilitate maintenance, time-delayed interlocks may be used to prevent access at granulators, agglomerators, and extruders;
- Use of screens or flaps to protect against material flying out from machinery feed openings;
- Use of Lock Out – Tag Out procedures, in addition to other guidance on the prevention and control of physical hazards as discussed in the General EHS Guidelines.

Chemical Hazards

Fire and Explosions

Fire in plastics manufacturing facilities may generate black acrid smoke and poisonous gases including carbon monoxide. The fires may spread quickly and be difficult to extinguish. Sources of ignition should be controlled by prohibiting smoking and hot work in high risk areas. Further information on emergency planning and response for fire and evacuation is contained in the **General EHS Guidelines**.

<u>Polymeric Dust</u>: Granulators produce fine dust that is often combustible. If suspended in air in high concentrations and ignited, an explosion may occur. High concentration of polymeric dusts may be generated close to the granulator when foamed rigid plastics are treated, and whenever coarse and fine granules are mechanically separated by sieving. Fine powders may accumulate on vertical walls, as well as on horizontal surfaces beyond the reach of conventional housekeeping. Although some polymeric dust is always formed, this becomes a hazard only if the materials are rigid (e.g. if its glass transition temperature is above room temperature). The severity of the hazard is higher for foamed materials due to their lower resistance to fragmentation.

Measures to prevent and control this hazard include the following:

- Facilities should be designed to avoid or minimize the creation of surfaces onto which polymer dust can settle or stick (e.g. due to electrostatic forces);
- Dust formation should be minimized through proper maintenance of cutter knives and settings;
- Sources of ignition should be eliminated. Metal parts should be grounded to reduce sparks formation due to static electricity. The use of open flames and smoking should be forbidden. A magnetic separator should be installed to reduce the risk of metals pieces entering the granulator.

Pentane: Raw expandable polystyrene (EPS) bead typically contains pentane, an extremely flammable gas. Pentane is released during storage and transportation of EPS and also from finished products for a short time after manufacture. Measures to prevent and control this hazard include the following:

- A work permit system should be established in areas where EPS is stored;
- Smoking should be prohibited anywhere EPS bead is manufactured, used, or stored;
- During pre-expansion, pentane vapor is mixed with steam which reduces its flammability. Pentane / steam vapor should be vented;
- Conveying ducts should be grounded, and product conveyed at slow speeds, to minimize static electricity generation;
- Expandable beads and pre-forms should be stored in a well-ventilated area. In the maturing silos, explosive mixtures may be generated in the head space. Silos should be grounded and ventilated to keep levels of pentane below the lower explosive limit. Finished goods should also be kept in a ventilated and fire proof place after molding;
- Electrical switches, lighting, motors and ventilation fans, and portable electrical devices should be suitable for use in areas where flammable vapors may be present;
- Hot-wire cutting may cause fires. The block transport system should be interlocked so that if the conveyor stops, the electrical supply to the wire is turned off;
- A gas monitor should be used to identify where pentane 'hot spots' are likely to occur, and to monitor concentrations;
- EPS handling areas should have a fire extinguishing system designed based on the results of a hazard analysis.

Air quality and Dermal Exposure

Dust may be generated during the machining and finishing of cured parts, and in the repair of damaged parts. Room temperature compounding for non-reactive processes may generate dust emissions. Dusts may be very fine and are potentially respirable. The presence of unreacted monomers may be of concern, especially for styrene-based resins.

The main sources of VOC emissions include low boiling point ingredients (e.g. solvents, trapped monomers) and thermal decomposition of the most labile compounds. The significance of the VOC releases increases with increasing temperature.

Thermoplastic polymers are generally not considered harmful to workers health. Resin formulations in reactive processes for thermoset plastic products, however, contain potentially hazardous materials. Epoxies and curing agents or hardeners have a low vapor pressure and usually do not present an airborne hazard unless in a mixture that is sprayed or cured at high temperatures. However, potential for dermal exposure is frequently high, particularly for the aromatic amines, which may permeate many of the commonly used protective gloves.

Isocyanates, present in polyurethanes, can represent a significant respiratory hazard, as well as a dermal hazard. For phenolic and amino resins, both phenol and formaldehyde represent an exposure hazard. The urea- and melamine-formaldehyde resins present similar hazards. Special attention is required in processes where heat decomposition of polyurethane products occurs, such as welding, heat removal of electrical insulating varnishes, and hot wire cutting of foams.

A number of solvents may be present in the reactive processing of thermosets. These may be introduced into the workplace as part of the resin or curing agent, during the manufacturing process, or as part of the cleanup process.

Occupational exposure prevention and control measures include the following:

- Isolation (e.g. isolated storage, separate process areas, enclosures, closed systems) and local exhaust ventilation should be adopted as the primary engineering controls in plastics and rubber manufacturing processes. Controls should be implemented in compounding and mixing areas; heated curing areas including autoclaves; finishing and repair areas; and controlling off-gases from exotherms;
- Adequate ventilation control systems and exhaust extraction with activated carbon adsorbers should be installed to prevent operator exposure to toxics, dusts and fibers. Adequate ventilation should be provided and should not be less than six air changes per hour;
- Adequate ventilation should be used in work areas to maintain the concentration of the isocyanates below 25 percent of the concentration that may cause harmful effects;
- The residence time and processing temperature of used polymer formulation in the barrel should be set to minimize plastics overheating and prevent fume generation;
- The 'burning out' of nozzles, blocked dies, injectors, material transfer valves, screen filter breaker plates, as well as the burning off solidified material, should be conducted under extraction, using pyrolysis units, or by other methods which prevent fume exposure;
- Whenever heat-sensitive materials (e.g. acetals and PVC) are processed, clear emergency procedures, including possible evacuation of the likely affected area, should be developed. Potential release of formaldehyde or hydrogen chloride (HCl) may result from the rapid degradation of the polymer in the barrel;
- Temperatures should be monitored and controlled in all sections of the production line. Adequate and reliable thermocouples should be installed to verify that the material is processed at the correct temperatures. Proportional-Differential-Integral controllers or PC controlled heating systems are recommended to minimize the cycling thermal fluctuation responsible for production instabilities and release of fumes.
- Gloves, protective clothing, eye protection, and other relevant PPE should be worn, especially when working with resins, curing agents, and solvents;
- Proper selection, use, maintenance, and cleaning of PPE. Provision of adequate gloves is especially important due to permeation characteristics of industrial chemicals;
- Respirators should be used where airborne solvent and dust levels are potentially high (e.g. during resin mixing, and finishing / repair activities), where large surface areas and significant hand work are involved, where exotherms are experienced, and whenever polyurethane-based materials are produced or handled at temperatures that might degrade the polymer;
- Operators should be provided with Material Safety Data Sheet (MSDS) from the supplier / distributor for the particular formulation used.

1.3 Community Health and Safety

Community health and safety impacts during the construction, operation, and decommissioning of metal, plastic, and rubber products manufacturing facilities are common to those of most industrial facilities, and are discussed in the **General EHS Guidelines**.

2.0 Performance Indicators and Monitoring

2.1 Environment

Emissions and Effluent Guidelines

Tables 5 and 6 present emission and effluent guidelines for metal, plastic, and rubber products manufacturing. Guideline values for process emissions and effluents in this sector are indicative of good international industry practice as reflected in relevant standards of countries with recognized regulatory frameworks. These guidelines are achievable under normal operating conditions in appropriately designed and operated facilities through the application of pollution prevention and control techniques discussed in the preceding sections of this document. These levels should be achieved, without dilution, at least 95 percent of the time that the plant or unit is operating, to be calculated as a proportion of annual operating hours. Deviation from these levels in consideration of specific, local project conditions should be justified in the environmental assessment.

Effluent guidelines are applicable for direct discharges of treated effluents to surface waters for general use. Site-specific discharge levels may be established based on the availability and conditions in use of publicly operated sewage collection and treatment systems or, if discharged directly to surface waters, on the receiving water use classification as described in the **General EHS Guidelines**.

Emissions guidelines are applicable to process emissions. Combustion source emissions guidelines associated with heat - and power-generation activities from sources with a heat input capacity equal to or lower than 50 Megawatt thermal (MWth) are addressed in the **General EHS Guidelines** with larger power source emissions addressed in the **EHS Guidelines for Thermal Power**. Guidance on ambient considerations based on the total load of emissions is provided in the **General EHS Guidelines**.

Table 5: Air Emission Levels for Metal, Plastic, and Rubber Products Manufacturing

Pollutants	Units	Guideline Value
VOCs – surface cleaning	mg/Nm^3	20-75(1)
VOCs – metal and plastic coating	mg/Nm^3	100 (up to 15 ton/y solvent consumption) 75 (more than 15 ton/y solvent consumption) 50 (drying processes)
VOCs – rubber conversion	mg/Nm^3	20(2)
TOC – rubber vulcanization	mg/Nm^3	80
Volatile Halogenated Hydrocarbons – metal surface treatments	mg/Nm^3	20
Particulate Matter – metal surface treatments	mg/Nm^3	5
Particulate Matter – plastic processing	mg/Nm^3	3
Hydrogen Chloride	mg/Nm^3	10
Nitrogen Oxides(3)	mg/Nm^3	350
Ammonia	mg/Nm^3	50

NOTES:
1. As 30 minute mean for contained sources. 20 mg/Nm^3 for waste gases from surface cleaning using VOCs classified as carcinogenic, mutagenic or toxic to reproduction (risk phrases R45, R46, R49, R60, R61) with mass flow greater than or equal to 10 g/hour; and / or halogenated VOC classified with risk phrase R40 and having a mass flow greater than or equal to 100 g/hour); 75 mg/Nm^3 for waste gases from other surface cleaning
2. Facilities with solvent consumption greater than 15 tonnes/year
3. Dry air at 11 percent O_2

Table 6: Effluent Levels for Metal, Plastic, and Rubber Products Manufacturing		
Pollutants	**Units**	**Guideline Value**
pH	S.U.	6 – 9
COD	mg/L	250
TSS	mg/L	50 25 (electroplating)
Oil and Grease	mg/L	10
Aluminum	mg/L	3
Arsenic	mg/L	0.1
Cadmium	mg/L	0.1
Chromium (total)	mg/L	0.5
Chromium (hexavalent)	mg/L	0.1
Copper	mg/L	0.5
Iron	mg/L	3
Lead	mg/L	0.2
Mercury	mg/L	0.01
Nickel	mg/L	0.5
Silver	mg/L	0.2
Tin	mg/L	2
Zinc	mg/L	2
Cyanides (total)	mg/L	1
Cyanides (free)	mg/L	0.2
Ammonia	mg/L	10 20 (electroplating)
Fluorides	mg/L	20
Phenols	mg/L	0.5
Total Nitrogen	mg/L	15
Total Phosphorus	mg/L	5
Sulfide	mg/L	1
Volatile Organic Halogens (VOX)	mg/L	0.1
Toxicity	To be determined on a case specific basis	
Temperature increase	°C	<3[a]

[a] At the edge of a scientifically established mixing zone which takes into account ambient water quality, receiving water use, potential receptors and assimilative capacity.

Resource Use

Table 7 provides examples of resource consumption indicators for energy and water in this sector. Industry benchmark values are provided for comparative purposes only and individual projects should target continual improvement in these areas.

Table 7 - Resource and Energy Consumption		
Inputs per unit of product	**Mass Load Unit**	**Industry Benchmark**
Energy (fabricated metal)		
Powder Metallurgy	GJ/t finished part	28-30
Cold/Warm Extrusion	GJ/t finished part	40-42
Hot Forging	GJ/t finished part	50
Machining	GJ/t finished part	80
Specific heat use – Steel Forging	MJ/ton/K	7
Power consumption - Metal heating	Kg/kWh	2.7 – 3.5
Welding (joining 4mm steel plate)	kJ/m	500 – 2,500
Energy Specific energy consumption (Plastics products)	kWh/kg	2.8 – 3.0
Compounding	kWh/kg	0.6-1.0
Extrusion and Blown Film	kWh/kg	1.0
Injection & Blow Molding	kWh/kg	3.0
Vacuum Thermoforming	kWh/kg	6.0 – 6.5
Foams Extrusion	kWh/kg	0.3
Rubber Specific energy consumption		
Electrical	kWh/ton	750
Thermal (Fuel)	Mcals/ton	1.25
Water **Water consumption** (Average per plant)	Ml/day	2 - 3

Sources:
US DoE. 2003; The Rubber Association of Canada. 1997; US EPA. 2005; EIPPCB. 2006

Environmental Monitoring

Environmental monitoring programs for this sector should be implemented to address all activities that have been identified to have potentially significant impacts on the environment, during normal operations and upset conditions. Environmental monitoring activities should be based on direct or indirect indicators of emissions, effluents, and resource use applicable to the particular project.

Monitoring frequency should be sufficient to provide representative data for the parameter being monitored.

Monitoring should be conducted by trained individuals following monitoring and record-keeping procedures and using properly calibrated and maintained equipment. Monitoring data should be analyzed and reviewed at regular intervals and compared with the operating standards so that any necessary corrective actions can be taken. Additional guidance on applicable sampling and analytical methods for emissions and effluents is provided in the **General EHS Guidelines**.

2.1 Occupational Health and Safety

Occupational Health and Safety Guidelines

Occupational health and safety performance should be evaluated against internationally published exposure guidelines, of which examples include the Threshold Limit Value (TLV®) occupational exposure guidelines and Biological Exposure Indices (BEIs®) published by American Conference of Governmental Industrial Hygienists (ACGIH),[4] the Pocket Guide to Chemical Hazards published by the United States National Institute for Occupational Health and Safety (NIOSH),[5] Permissible Exposure Limits (PELs) published by the Occupational Safety and Health Administration of the United States (OSHA),[6] Indicative Occupational Exposure Limit Values published by European Union member states,[7] or other similar sources.

Accident and Fatality Rates

Projects should try to reduce the number of accidents among project workers (whether directly employed or subcontracted) to a rate of zero, especially accidents that could result in lost work time, different levels of disability, or even fatalities. Facility rates may be benchmarked against the performance of facilities in this sector in developed countries through consultation with published sources (e.g. US Bureau of Labor Statistics and UK Health and Safety Executive)[8].

Occupational Health and Safety Monitoring

The working environment should be occupational hazards relevant to the specific project. Monitoring should be designed and implemented by accredited professionals[9] as part of an occupational health and safety monitoring program. Facilities should also maintain a record of occupational accidents and diseases and dangerous occurrences and accidents. Additional guidance on occupational health and safety monitoring programs is provided in the **General EHS Guidelines**.

[4] Available at: http://www.acgih.org/TLV/ and http://www.acgih.org/store/
[5] Available at: http://www.cdc.gov/niosh/npg/
[6] Available at: http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9992
[7] Available at: http://europe.osha.eu.int/good_practice/risks/ds/oel/
[8] Available at: http://www.bls.gov/iif/ and http://www.hse.gov.uk/statistics/index.htm
[9] Accredited professionals may include Certified Industrial Hygienists, Registered Occupational Hygienists, or Certified Safety Professionals or their equivalent.

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Annex A: General Description of Industry Activities

Metal Products Manufacturing

Metal manufacturing operations addressed as part of these Guidelines can be grouped into two main phases, namely forming (including thermal treatments), and finishing (including surface treatments, metal cleaning and coating). Metal casting is addressed in the **EHS Guidelines for Foundries**.

Thermal Treatments and Forming

Heat treating involves the modification of the physical properties of the metal product through the application of controlled heating and cooling cycles (e.g. quenching, tempering, and normalization). The metal may be hot-worked, cold-worked, or both, to produce specific shapes. During cold deformation, an intermediate heat treatment (e.g. annealing) may be applied to eliminate hardening and maintain the malleability of the metallic material, and this step may repeated a number of times depending on the specific characteristics of the alloy. Following heat treatment, the surface is cleaned of rust, scales, and scraps. Metal fabricating processes usually employ cutting fluids (e.g. ethylene glycol), degreasing and cleaning solvents, acids, alkalis, and heavy metals. Oils are typically used when forming and cutting the metal.

Welding

Welding is the main technique to join separate metallic parts. There are more than twenty types of welding techniques but the two main technologies, covering approximately the 70 percent of all welding activities, are manual metal arc welding (where a flux-coated electrode is used) and gas metal arc welding (e.g. TIG or MIG / MAG), where the wire electrode is gas-shielded from external atmosphere. Other welding techniques include furnace and oxyacetylene flame, plasma torch, laser, and electron beam.

Surface Preparation

Prior to finishing treatments (e.g. coating, painting, and chemical deposition), metal surfaces are prepared through cleaning and other techniques to create the right chemical conditions for the finishing treatment. Surface preparation may involve simple abrasive blasting using high pressurized water (with abrasive powders, such as alumina or silica), air blast, and / or abrasive paper (with or without water as a lubricant and cooler).

Alkaline cleaning solutions consist of three basic components: (1) builders (e.g. alkali hydroxides and carbonates), which make up the largest portion of the cleaner; (2) organic or inorganic additives, which promote better cleaning or act to affect the metal surface in some way; and (3) surfactants. Alkaline cleaning is often assisted by mechanical action, ultrasonics, or by electrical potential (e.g. electrolytic cleaning). Alkaline cleaning may also be utilized for the removal of organic soils.

Acid cleaning, or pickling, may be used to prepare the surface of metal products by chemically removing oxides and scale from the surface of the metal. Acids employed include hydrochloric, sulfuric, hydrofluoric, and nitric acid. For instance, most carbon steel is pickled with sulfuric or hydrochloric acid, while stainless steel is pickled with hydrochloric or hydrofluoric acids. Although similar, acid pickling is commonly used to remove the scale from semi-finished mill products, whereas acid cleaning is used for near-final preparation of metal surfaces before electroplating, painting, and other finishing processes.

Lastly, ccomplex, multi-stage chemical cleaning processes involve the application of organic solvents to degrease the surface of the metal. Emulsion cleaning, for example, uses common organic solvents (e.g. kerosene, mineral oils, and glycols) dispersed in an aqueous medium.

Metal Finishing

Anodizing

Anodizing is an electrolytic process which converts the metal surface to an insoluble oxide coating. Aluminum is the most frequently anodized material. Common aluminum anodizing processes include chromic acid, sulfuric acid, and boric-sulfuric anodizing. The sulfuric acid process is the most common method. Following anodizing, metal parts are typically rinsed, and sealed. Common sealants include chromic acid, nickel acetate, nickel-cobalt acetate, and hot water.

Chemical Conversion Coating

Chemical conversion coating includes chromating, phosphating, metal coloring, and passivating operations. Chromate conversion coatings are produced on various metals through chemical or electrochemical treatment. Solutions, usually hazardous, containing hexavalent chromium and other compounds, react with the metal surface to form a layer containing a complex mixture of compounds consisting of chromium, other constituents, and base metals. Phosphate coatings may be formed by the immersion of steel, iron, or zinc-plated steel in a diluted solution of phosphate salts, phosphoric acid, and other reagents to condition the surfaces for further processing.

Electroplating

Electroplating is the production of a surface coating of one metal upon another through electro-deposition. Electroplating activities involve applying predominantly inorganic coatings onto surfaces. The most commonly electroplated metals and alloys include brass (copper-zinc), cadmium, chromium, copper, gold, nickel, silver, tin, and zinc. During electroplating, metal ions in aqueous solution are reduced on the work pieces undergoing plating. The metal ions in the solution are usually replenished by the dissolution of metal from solid metal anodes, or by direct replenishment of the solution with metal salts or oxides. Cyanide, usually in the form of sodium or potassium cyanide, is often used as a complexing agent for cadmium and precious metals electroplating, and to a lesser degree, for other solutions such as copper and zinc baths.

Painting

Painting involves the application of predominantly organic coatings to a work piece for protective and / or decorative purposes. Paint is applied in various forms, including dry powder, solvent-diluted formulations, and water-borne formulations. Various methods of application are used (e.g. spray painting and electro-deposition).

Other Metal Finishing Techniques

Polishing is an abrading operation used to remove or smooth out surface defects that adversely affect the appearance or function of a part. Following polishing operations, cleaning and area washing can produce wastewaters containing metals. Hot dip coating is the coating of a metallic work piece with another metal to provide a protective film by immersion into a molten bath. Galvanizing (hot dip zinc) is a common form of hot dip coating. Water is used for rinsing following pre-cleaning and for quenching after coating. Wastewaters generated by these operations often contain metals.

Plastics and Rubber Products Manufacturing

Plastics

Manufacturing of plastic products may or may not involve chemical reactions between components. *Non-reactive processes* are related to thermoplastic polymers where the product is obtained through a sequence of stages involving heating of the raw material until molten; shaping through a die or in a mold; and cooling to room temperature to obtain a solid product.

Reactive processes involve a polymerization reaction in the mold between low molecular weight compounds (monomers or pre-polymers) in the presence of suitable catalysts and additives. Reactive processes are necessary to manufacture products involving thermosetting polymers. The manufacture of thermoplastic polyamides by the fast anionic polymerization of lactams with Reaction Injection Molding (RIM) technology also belongs to the reactive process stream.

Typical examples of the above two families of polymeric materials include:

- Thermoplastics**:** Polyolefins: polyethylenes (HDPE, LDPE, LLDPE), polypropylenes, styrenics (HIPS, ABS), vinyls (PVC), acrylics (PMMA), cellulosics, fluoroplastics (Teflon, PVDF), polyesters (PET, PBT), polycarbonates, polyethers, polyamides (Nylon 6, Nylon 6,6), polyacetals, thermoplastic rubbers (SBS, SIS) and polyimides;
- Thermosets: Polyurethanes, unsaturated polyesters, epoxydes, phenolics.

Non-Reactive Plastic Manufacturing Processes

This is the most common procedure for polymer manufacturing and involves all types of processing in which the products are obtained through "non-reactive" processes. The main raw material, the polymer, is supplied in the form of pellets or powders obtained through polymerization reactions carried out as a separate chemical process, usually in large scale production facilities. If the polymer does not already contain the required additives, the compounding of the polymer with the appropriate formulation is performed prior to molding an d often at a different site.

Additives are mixed with the plastic materials in the compounding / mixing step of the production chain to give the final product the desired characteristics (some of these additives may also be applied to the shaped product during the finishing process). Plastic additives and their functions, in terms of their effect on the final product, are listed below:

- Lubricants assist in easing the flow of the plastic during the molding and extruding processes;
- Antioxidants inhibit the oxidation of plastic materials;
- Antistats impart a degree of electrical conductivity to the plastic compound, preventing electrostatic charge accumulation on the finished product;
- Blowing agents (foaming agents) produce a cellular structure within the plastic mass;
- Colorants impart color to the plastic resin;
- Nucleating agents and clarifiers speed-up the solidification process during cooling of the molten polymer and increase the transparency of the product if the polymer is crystallizable;
- Flame retardants decrease flammability risks;
- Heat stabilizers assist in maintaining the chemical and physical properties of the plastic by protecting it from the effects of heat;
- Impact modifiers prevent brittleness and increase the resistance of the plastic to cracking;
- Organic peroxides initiate or control the rate of polymerization in thermosets and thermoplastics;
- Plasticizers increase the plastic product's flexibility and workability;
- Ultraviolet stabilizers (UV light absorbers) absorb or screen out ultraviolet radiation, preventing degradation of the plastic product.

The main processes used in the manufacture of thermoplastic products include: (1) imparting the appropriate characteristics to the plastic resin with chemical additives; (2) converting plastic materials in the form of pellets, granules, powders, sheets, fluids, or preforms into either intermediate or final formed plastic shapes or parts via molding operations; and (3) applying finishing treatments to the product. Granulators are used to reduce un-degraded and uncontaminated rejected parts and scrap material into chips or pellets with dimensions suitable for return to the extruder (mixed with virgin feed).

After adding the necessary additives, the plastic mixture is formed into intermediate or final plastics products. To form solid plastics products, a variety of molding processes are used, as described below.

Injection molding: Plastic granules or pellets are heated and homogenized by an Archimedean screw, rotating in a heated cylinder (the barrel), which also pumps the molten polymer towards the end of the screw. When enough fluid has been obtained, a hydraulic ram injects it into a relatively cold mold where the plastic takes the shape of the mold as it solidifies.

Extrusion: Plastic pellets or granules are fluidized, homogenized, and formed continuously as the extrusion machine feeds them through a die. Extruding is often combined with post-extruding processes (e.g. blowing, thermoforming, or punching).

Blow molding: In blow molding an extruded plastic tube is trapped within a hollow mold, and compressed air is injected to cause the still-molten plastic to form to the mold. After forming the solid product is ejected from the mold.

Films are formed by extruding a tube, which is then inflated to form a thin vertical film bubble, and cooled and rolled for subsequent processing.

Thermoforming: Heat and pressure (or vacuum) are applied to plastic sheets placed over molds, to form the sheet into the shape of the mold.

Rotational molding: Finely ground plastic powders are heated in a rotating mold to obtain a melt with low viscosity. When the inner surface of the revolving mold is evenly coated with the molten resin, the mold is cooled and a scrap-free hollow product is obtained.

Compression and transfer molding: Plastic powder or a preformed plastic part is plugged into a mold cavity and compressed with pressure and heat until it takes the shape of the cavity. Transfer molding is similar, except that the plastic is liquefied in one chamber and then injected into a closed mold cavity by a hydraulically operated plunger.

Calendering: Plastic parts are squeezed between two rolls to form a thin, continuous film.

Reactive Plastic Manufacturing Processes

To produce a thermoset plastic material, liquid resins are combined with a catalyst. The mixing of ingredients is followed by a curing step to produce a cured or finished part. Once cured, the part cannot be changed or reformed, except for finishing treatments. Resins used for thermoset plastic products include urethane, epoxy, polyester, acrylic, phenolic and amino resins. Fillers and additives are added to the resin-catalyst mixture prior to molding to increase product strength and performance and to reduce cost. Most thermoset plastic products contain large amounts of fillers (up to 70 percent by weight). Commonly used fillers include mineral fibers, clay, glass fibers, wood fibers, and carbon black. Several other ingredients are used, including curing agents, accelerators, reactive diluents, and pigments.

Various molding options can be used to create the intermediate or final thermoset product, including vacuum, press, and rotational molding, hand lamination, casting and encapsulation, spray-up lamination, resin transfer molding, filament winding, injection molding, reaction injection molding, and pultrusion.

Foamed Plastics

Manufacturing foamed plastics products involves slightly different forming processes than those described above. The three types of foam plastic are blown, syntactic, and structural. Blown foam is an expanded matrix, similar to a natural sponge. Syntactic foam is the encapsulation of hollow organic or inorganic micro spheres in the plastic matrix, and structural foam is a foamed core surrounded by a solid outer skin.

All three types of foam plastic can be produced using processes such as injection, extrusion, and compression molding to create foam products in many of the same shapes as solid plastics products. Structural foam plastic is made by injecting molding liquid resins that contain chemical blowing agents. After the solid or foam plastic shape is created, post-forming operations such as welding, adhesive bonding, machining, and surface decoration (e.g. painting) are used to finish the product.

Rubbers

Although rubber product manufacturing is very diverse, there are several basic, common processes, as below.

*Mixing***:** The rubber product manufacturing process begins with the production of a rubber mix from polymers (e.g. natural and / or synthetic rubber), carbon black (the primary filler used in making a rubber mixture), oils, and miscellaneous chemicals. The miscellaneous chemicals include processing aids, vulcanizing agents, activators, accelerators, age resistors, fillers, softeners, and specialty materials (including retarders, colorants, blowing agents, dusting agents, and anti-odorants, among others).

Rubber mixes differ depending upon the desired characteristics of the product. The appropriate ingredients are weighed and loaded into an internal mixer known as a "Banbury" mixer. The area where the chemicals are weighed and added to the mixer is called the compounding area. The polymers and other chemicals are manually introduced into the mixer hopper, while carbon black and oils are often injected directly into the mixing chamber from bulk storage systems. After mixing, the rubber is then cooled.

Milling: The mixed rubber mass is discharged to a mill or other piece of equipment that forms it into a long strip or sheet. The hot, tacky rubber then passes through a water-based "anti-tack" solution that prevents the rubber sheets from sticking together as they cool to ambient temperature. The rubber sheets are placed directly onto a long conveyor belt that, through the application of cool air or cool water, lowers the temperature of the rubber sheets. After cooling, the sheets of rubber are sent through another mill. These mills warm up the rubber for further processing on extruders and calenders. Some extruders can be cold fed rubber sheets, making this milling step unnecessary.

Extruding: Extruders transform the rubber into various shapes or profiles by forcing it through dies via a rotating screw. Extruding heats the rubber, which remains hot until it enters a water bath or spray conveyor where it cools.

Calendering: Calenders receive hot strips of rubber from mills and squeeze them into reinforcing fibers or cloth-like fiber matrices, thus forming thin sheets of rubber-coated materials. Calenders are also used to produce non-reinforced, thickness-controlled sheets of rubber.

Building: Extruded and calendered rubber components are combined (layered or built-up) with wire, polyester, aramid, and other reinforcing materials to produce various rubber products. Adhesives, called cements, are sometimes used to enhance the bonding of the various product layers, or the rubber surfaces are etched using solvents to improve adhesion. Bonded metal / rubber products (e.g. auto suspension components, engine mountings) are also built-in during this phase.

Vulcanizing: Most rubber products require vulcanization (curing) or cross-linking. This process occurs in heated compression molds, steam-heated pressure vessels (autoclaves), hot air and microwave ovens, or various molten and fluidized bed units. The assembled product (e.g. a tire) is held at an elevated temperature, in a mold, to permit vulcanization to occur after the assembly takes the shape of the mold. During the curing process, the polymer chains in the rubber matrix cross-link to form a final product of durable, elastic, thermoset rubber. The cross-links in the rubber matrix provides the material with its characteristic feature of highly reversible elastic behavior.

Finishing: Finishing operations are used to prepare the products for delivery to the end user. Finishing operations for tire-making include balancing, grinding, printing, washing, wiping, and buffing.

Dipped Latex Technology

Rubber products (e.g. rubber gloves, catheters and other surgical appliances) are manufactured using the dipped latex technology with lattices of isoprenic natural rubber. Concentrated latex is produced through four techniques, namely centrifugation, evaporation, creaming and electro-decantation. Soft, rubbery alternatives to natural rubber latex have been developed and are being used, especially for gloves. These include nitrile rubber, synthetic latex (which has no proteins), polyvinyl chloride (PVC), styrenic elastomers, polyurethane, and silicone.

For both natural rubber latex and synthetic rubber, auxiliary ingredients (e.g. vulcanizing agents, vulcanization accelerators, activators, retarders, auto-oxidants, stabilizers, thickeners, and coagulants) are needed to mix with the latex to achieve the appropriate type of quality products.