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U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
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ABSTRACT

The secondary metals industry associated with the recycling of ferrous scrap is tied to the development in the 1850's of the acid-Bessemer furnace, the first large capacity steelmaking process. Within twenty-five years of this development, the recycling of ferrous scrap became an established industry. Changes in steelmaking technology since World War II, especially since the 1960's, are impacting the traditional ferrous scrap industry. The increased demand for old scrap is due to growth in electric-arc furnace steelmaking capacity, reduced availability of home scrap and prompt industrial scrap, and larger scrap exports. Ferrous scrap recovered from municipal solid waste is one of the new sources of old scrap that may satisfy these increased demands. Systems for the recovery of the ferrous fraction from municipal solid waste have been developed, although increased usage of municipal ferrous scrap has been very slow due to institutional and technical barriers. The technical barriers posed by the physical and chemical characteristics of municipal ferrous scrap strongly inhibit the development of markets for this new material. The real and potential markets for increased consumption of municipal ferrous scrap are discussed in terms of these barriers together with the important role of standards for municipal ferrous scrap in improving communications between buyers and sellers.

Introduction

In any analysis of recycling, it is necessary to place in perspective the industries which consume or could consume the recycled material and the existing relationship between the suppliers of the recycled material, the secondary materials industry, and these consumers. This discussion, limited to iron and steel scrap (that is, ferrous scrap), focuses on the individual markets for scrap, their historical development, and the recent changes in the supply and demand of scrap in these markets. The types of ferrous scrap are related to their origins, availability, and extent of present recycling. Ferrous scrap recovered from municipal solid waste, a new source of ferrous scrap, is discussed in terms of the traditional sources of scrap, its role as a major contributor to the supply of scrap, and the effect of impediments to increased usage of this type of scrap. Finally, it is necessary to establish some definitions of terms for this discussion. Virgin or primary metals are produced from ores. Scrap or secondary metals are derived from primary metals or previously fabricated metal products. This scrap can be utilized in place of virgin metal or the scrap can replace some other type of scrap in manufacturing a new product.

Ferrous Scrap History

Ferrous scrap is consumed by industries other than iron and steel producers, iron foundries, and ferroalloy producers. The detinning industry and the copper precipitation industry both use ferrous scrap which has special characteristics appropriate for these two uses. In terms of annual scrap consumption, however, iron and steel producers are the dominant force in the ferrous scrap market as seen in Table 1.

In the iron and steel industry, the first efforts to make use of scrap iron or ferrous scrap in the production of iron and steel were closely associated with the development in the 1850's of the first modern steelmaking process, the acid-Bessemer process. In the early part of the nineteenth century, steel was made by the crucible process with outputs of about 45 kg per hour. The new Bessemer process could produce 4500 kg in one-half hour so large scale production of steel was now possible.(5) However, the acid-Bessemer process had two drawbacks which eventually led to its 20th century demise. First, although the steel produced by this process was suitable for many structural applications and the railroad industry, the refining process in this air-blown furnace could not reduce the phosphorus and nitrogen levels sufficiently to produce the high quality steel needed by the automotive industry. Second, the acid-Bessemer furnace could not accept more than about six percent ferrous scrap as part of the furnace charge. This limited both the raw materials that could be used and the grades of steel that could be produced. From the 1850's on, substantial amounts of scrap iron and steel accumulated from the expanding iron and steel-making industry, fabricating operations, and worn out or obsolete iron and steel products from the railroads and other industries. This ferrous scrap, readily available and inexpensive, did not yet have a market because of the absence of a steel refining process which could consume substantial quantities of scrap.

In the 1860's, Siemens invented the regenerative heating principle for steelmaking which permitted heating solid pig iron, iron ore, and scrap to high temperatures for refining and the modern open-hearth steelmaking process was born.(5) The solid charge or feed stock for the open-hearth could be all scrap and thus the open-hearth furnace had a considerably greater capacity to consume ferrous scrap than the acid-lined Bessemer furnace. Basic-lined open-hearth furnaces, which permitted control of the sulfur and phosphorus content of steel, were first installed in the late 1880's, and were able to make use of the extensive U.S. iron ore deposits whose phosphorus content was too high for the acid-Bessemer furnace. Growth of the open-hearth process was rapid and by 1900 open-hearth steel accounted for one-third of the U.S. steel production. By 1908, open-hearth steel tonnage exceeded Bessemer steel production(6) and remained the dominant steelmaking process in the U.S. until 1970. Thus, within twenty-five years of the development of modern steelmaking technology, a large market for ferrous scrap was developed.

There have been two other modern steelmaking developments which have had different impacts on the ferrous scrap industry. First, in 1878 Siemens built the first electric-arc furnace for making steel. Advantages of this process were low capital costs per ton of capacity and a charge or feedstock that was usually 100 percent solid iron or scrap, so molten pig iron from a blast furnace was not needed. Until World War II, electric-arc furnaces produced primarily tool steels, stainless steels, and other high alloy steels in small furnaces ranging up to 18 metric tons in capacity and had only a small impact on the ferrous scrap market. Electric furnace steel production had grown so slowly that by 1955 it represented less than seven percent of total steel production. In the years following World War II, numerous large capacity furnaces, up to 360 metric tons in size, were installed and many were used to produce the common carbon steel grades. As a result, by 1969, electric furnace steel production increased to more than 14% of the annual steel production with a corresponding increase in scrap consumption.(7) By 1978, electric furnace steel production accounted for about 23% of the total U.S. steel production.(1)

The second development resulted in the re-birth of the pneumatic Bessemer-type process. Although the early developers of pneumatic steelmaking recognized the value of blowing oxygen instead of air to oxidize impurities and adjust the steel chemistry, the technology for producing large quantities of low cost oxygen was not available until after World War II. Thus, the inability of air, containing about 80% nitrogen, to refine steel to sufficiently low nitrogen levels combined with the difficulty of removing phosphorus in the air-blown, acid-lined furnace, resulted by 1950 in the decrease of Bessemer steel production to less than five percent of the U.S. total production.

After World War II, conditions developed in Europe which required the production of a low nitrogen steel. At that time, open-hearth scrap was scarce, the available blast furnace pig iron was not chemically suitable for the bottom-blown Bessemer furnace, and high purity, low cost oxygen was available. A steelmaking process, known as the basic oxygen process or LD process, was developed in Austria over the years 1949 to 1952 which used top-blown oxygen instead of air as the oxidizing or fuel agent in a basic-lined Bessemer-type furnace and consumed less scrap per furnace charge than the open-hearth furnace. Steel low in phosphorus and nitrogen could be produced more rapidly and at lower costs than in the open-hearth furnace; the capital costs of these basic-oxygen furnaces (BOF) were lower than new open-hearth construction.(6,8) By 1970, the production of BOF steel surpassed open-hearth steel and became the dominant steelmaking process in the U.S.

Iron foundries originally used hot metal from blast furnaces or solidified pig iron as the primary charge in the cupola iron-making furnace.(9) However, by the early 1950's, ferrous scrap had replaced about 40% of the cupola charge. Further, during the early 1960's, concurrent with the growth in electric-arc steelmaking capacity, iron foundries also added electric-arc furnaces for the production of cast iron.(3) By 1973, electric-arc furnaces produced 23% of the cast iron while cupola furnace production declined to 73%.(10) Total production of ferrous castings in 1979, including gray cast iron, ductile cast iron, and malleable cast iron, totaled about 15.5 million metric tons with gray iron representing 72% or about 11 million metric tons.(2) Over 90% of the furnace charge in the gray cast iron industry is ferrous scrap.

The copper precipitation industry uses ferrous scrap for a precipitating agent in processing low grade copper ores and mine tailings. The copper-bearing material is dissolved in sulfuric acid to produce copper sulfate. Light gauge ferrous scrap is added to the copper sulfate solution causing the copper to be chemically displaced by the iron forming a copper precipitate. The principal sources of the light gauge ferrous scrap are the ferrous residue from the solid waste incinerators and detinned ferrous scrap from the detinning industry, another consumer of ferrous scrap. Detinners process only tin-plate scrap, usually from can manufacturers and steel tin-plate mills, in order to reclaim the tin and as a by-product generate a high quality "tin-free" ferrous scrap which can be consumed directly by the iron and steel industry as well as by the copper precipitation industry. (The secondary metals industry designation for this detinned can scrap is No. 1 bundles.) In the detinning process, the tin coating is dissolved in hot sodium hydroxide. The tin is then electrolytically precipitated from the sodium stannate solution.

Sources of Ferrous Scrap

Traditionally, ferrous scrap has been called either home scrap, prompt industrial scrap, or old scrap. Home scrap, or revert scrap, generated during the production of steel or cast iron, is always recycled because its history and chemistry are well known. Manufacturing industries also produce scrap during the fabrication of various industrial, commercial, or consumer steel products. This scrap called prompt industrial scrap or new scrap, is also widely recycled because its chemical and physical characteristics can be well documented, although in some cases, additional processing such as detinning or compacting must be carried out to put the scrap in a form suitable for recycling. The availability of prompt industrial scrap is directly related to the level of industrial economic activity. Prompt industrial scrap producers usually cannot allow it to accumulate because of storage requirements and costs of inventory control. Thus, it is rapidly available at current prices to the steelmaker or ferrous scrap industry.

All other ferrous scrap is included in the third category called old scrap, obsolete scrap, or post-consumer scrap. This category includes all goods or products in which the iron content can at least in theory be recovered and recycled. The major types of old scrap recycled in the United States are railroad, machinery, and automotive while in foreign countries with lower labor costs, shipbreaking is a major source of obsolete scrap. Although automotive scrap, that is, recycled automobiles, has been a traditional source of obsolete scrap, advances in recycling technology during the early 1960's greatly enhanced the value and importance of this ferrous scrap. Ferrous scrap recovered from municipal solid waste (MSW), sometimes called MSW magnetics or municipal ferrous scrap (MFS), is a new non-traditional source of obsolete scrap. In terms of quality, desirability, and cost, home scrap generally ranks highest; prompt industrial scrap second; and old scrap, including municipal ferrous scrap last. This lower ranking of old scrap is a direct consequence of its greater heterogeneity in chemical and physical characteristics making it more costly to process.

Recent estimates(9,11,12) suggest that from 9 to 11 million metric tons per year of ferrous scrap are discarded into municipal solid waste and yet less than two percent, i.e. 450,000 metric tons has ever been recovered in any year. In 1979, about 180,000 metric tons of municipal ferrous scrap was recovered.(13) Although the composition of municipal solid waste exhibits regional, seasonal, and other variations, some broad ranges for important components have been identified as shown in Table 3. Overall, approximately 80% of MSW is combustible, including about 20% moisture. Ferrous scrap accounts for about 85% of the noncombustibles. Beverage and food cans, (excluding all-aluminum cans), make up between 50% and 90% of the ferrous fraction in municipal solid waste.

Role of Ferrous Scrap in Modern Steelmaking Processes

Modern steelmaking processes can be divided into two categories based on materials flow. One category contains the blast furnace together with the open-hearth and/or BOF refining furnaces, and the second category contains the electric refining furnaces.

In an integrated steel mill, where iron ore is converted into finished steel products, the ore is chemically reduced with coke and limestone in a blast furnace to molten pig iron or hot-metal. The hot metal is combined with ferrous scrap in an open-hearth furnace or a BOF and refined until the desired grade of steel is produced. The open-hearth furnace has the greatest flexibility in its consumption of scrap because a portion of the heat needed to melt the scrap is supplied by an external fuel. It can process 100% hot metal, 100% scrap or solid pig iron or any combination in-between. Usually 40% to 60% scrap is charged with hot metal. However, the importance of the open-hearth process is rapidly declining so its scrap flexibility is being lost. Scrap usage in the BOF is limited because the oxidation of carbon and silicon is the only source of heat for melting the scrap. Without preheating, the maximum amount of scrap per charge consumed in the BOF is about 33%.

The electric-arc furnace, like the open-hearth furnace, refines a material charge with any ratio of hot metal to solid metal, but typically operates with a solid charge of almost all scrap. The rapid increase in electric furnace capacity in the last two decades has been paced by the growth of mini-mills, small capacity steel mills using only electric-arc furnaces based on 100 percent scrap, and expansion of electric-arc furnace capacity by integrated steel mills producing carbon steels. Mini-mills have greater geographic independence than integrated steel mills because they are not dependent on sources of iron ore, coke, and limestone. Thus, mini-mills often produce steel products for local or regional markets and can adapt more readily to changes in the steel market. Some integrated steel mills have also substantially increased electric-arc steel production when hot metal shortages developed as a result of the use of BOF units with their higher consumption of hot metal. In addition, the high cost per ton of annual capacity of constructing a new or "greenfield" integrated steel mill, which includes coke ovens, blast furnaces, and BOFs, has limited the options available for increasing steelmaking capacity. Growth in electric furnace capacity has led to increased demand for ferrous scrap.

According to Table 4, steel industry data for 1978 show that the basic oxygen furnaces produced about 61% of domestic steel, electric-arc furnaces about 23%, and open-hearth furnaces about 16%.(1) However, about 49% of the total ferrous scrap consumed went to electric-arc furnaces, 34% to the

BOF, and almost 17% to open-hearth furnaces. Over 52% of the total steel production was from ferrous scrap. By 1988, the steel industry forecasts the demise of the open-hearth furnace process with both its capacity and any additional growth in steel production being met by the BOF and electric-arc furnaces. The BOF will be expected to account for about 68% of the total steel production and electric-arc furnaces the remaining 32%. In terms of ferrous scrap consumption, however, electric-arc furnaces will use 65% of the total scrap and the BOF will use only 35%. It should be noted that in 1978, 1.31 metric tons of scrap were consumed by electric-arc furnaces for every ton of scrap used by the basic oxygen furnaces, while the forecast for 1988 shows 1.69 metric tons of scrap used by electric-arc furnaces per ton of scrap used by the BOF. Thus, the growth in scrap consumption will occur primarily through growth in electric-arc furnace capacity. Further, as open-hearth capacity decreases, additional hot-metal capacity will be freed to supply the BOF. Thus BOF scrap usage as a percent of the charge may fall slightly.

Historically, significant changes in the primary steelmaking processes have strongly affected the role of ferrous scrap in modern steelmaking technology because of the key part played by ferrous scrap as a source of iron. The rapid displacement of the open-hearth furnace by the BOF from 1956 to 1970 increased the demand for hot metal and reduced the demand for obsolete scrap. The reduced scrap needs in the BOF were more easily met by the supply of home scrap and prompt industrial scrap. This transition from open-hearth dominance to BOF dominance was accompanied by an increase in the cost of molten pig iron and a decrease in the cost of ferrous scrap.(15) The availability of lower cost scrap was a main contributing factor to almost doubling electric-furnace steel production, especially for carbon steel grades, from 1956 to 1970.

Typically, rising steel production increases the demand and cost of scrap and vice versa when steel production falls. The supply of prompt industrial scrap, however, is not strongly related to scrap prices but, rather, is closely related to the level of steel consumption. The supply of obsolete scrap, on the other hand, is more closely tied to scrap prices. A study from 1950 to 1973 concluded that over the short term, the supply of obsolete scrap was directly proportional to the price.(16) The price of ferrous scrap is highly volatile. Contributing to this instability in the short term are several characteristics of typical scrap purchase agreements.(10) Ferrous scrap usually is purchased on the basis of 30 day or 60 day delivery contracts so that short term changes in steel production directly impact the demand for scrap. Further, the basis for acceptance in terms of quality control is often not consistent so that scrap buyers can hedge against short term decreases in price at the time of delivery by rejecting the scrap shipment based on quality. The weekly composite price per metric ton for the largest tonnage grade of ferrous scrap reflects these price fluctuations, shown in Figure 1 for the past four years. The maximum price change as a percent of the annual low price was 56% for 1977, 23% for 1978, 48% for 1979, 57% for 1980, and 38% for 1981.(17) Long term effects on the price of scrap include international demand and technology changes that affect both scrap sellers (auto shredders) and scrap buyers (electric furnaces). Since 1970, changes in the scrap market occurred which have led to some recent anomalies in the domestic supply-demand relationship for ferrous scrap.

Excess scrap accumulated during periods of low steel production is consumed during high demand years. Low ferrous scrap consumption during 1971 and 1972 generated a scrap inventory that supplied the strong domestic and export demand for scrap in 1973 with only small price increases. In 1974 rapid increases in scrap prices occurred because of dwindling inventories. Again, reduced scrap consumption in 1976 and 1977 provided a supply of scrap that satisfied the high demand for scrap, particularly for export, during 1979 and 1980. However, during two periods in the years 1979 and 1980, scrap prices rose substantially at the same time domestic scrap demand decreased. One factor contributing to the unusual behavior was the increased export demand for scrap. From 1978 to 1980, about 9 million metric tons of scrap was exported each year, while the average for the previous ten years was about 7.5 million metric tons per year, or 20% less. Another explanation, one favored by steel industry consumers of scrap, is the belief that the demand for obsolete scrap exceeds and will continue to exceed the supply that is economically available.(18) This demand is attributed to increases in the number of mini-mills; expansion of electric-furnace capacity by domestic integrated steel producers; increased electric-arc furnaces capacity by foreign steelmakers thus increasing the number of foreign countries buying U.S. scrap. The position of the secondary metals industry is that the continued high demand and high price for scrap will in the long run result in an increased recovery of obsolete scrap, and that the present domestic inventory of obsolete scrap is more than sufficient to meet the future needs of both the domestic and the export scrap markets. The potential market for new sources of obsolete scrap, including municipal ferrous scrap, includes therefore not only domestic markets but also a growing export market.

Recycling Ferrous Scrap from Municipal Solid Waste

The development in the 1960s of a national interest in recovery of various materials including ferrous scrap from municipal solid waste, resource recovery, was a response to increasing solid waste disposal problems.(12) Some communities were running out of landfill capacity. Traditional solid waste incineration was declining due to air pollution control regulations. Many existing sanitary landfills were not "sanitary" and were being closed. New landfill sites were becoming more difficult to locate because of land availability or the inability of proposed sites to satisfy health and safety regulations. Thus, the incentive for the development of a resource recovery industry generating ferrous scrap as one of many products was different from the forces which created a secondary metals industry marketing ferrous scrap from traditional sources. Resource recovery offered the opportunity to achieve a significant reduction in the volume of municipal solid waste. Raw solid waste could be separated into glass, ferrous, aluminum, and the organic or combustible fractions; a process called front-end separation. The sale of the materials would provide income to help offset separation costs and disposal of the unsalable residue. Recycling of ferrous scrap from municipal solid waste cannot be a major materials supplier because the quantities of ferrous scrap cannot provide enough material to satisfy annual consumption. However, municipal ferrous scrap has the potential to supply up to 10% of the nation's annual scrap consumption.

A more recent incentive for recycling can be traced to the oil embargo in the early 1970s and the emphasis on energy conservation and development of alternative energy sources. The combustible fraction in municipal solid waste is receiving considerable attention as either a supplementary boiler fuel or as the only fuel in mass-burning facilities for the generation of steam and/or electricity. Ferrous scrap and other non-combustible materials can be removed from the solid waste as the waste is processed into a form suitable for a fuel, or if the unseparated solid waste is used as the fuel, the ferrous scrap can be separated and recovered from the boiler ash.

Finally, economic value and/or ease of recovery can be strong motivating factors for recycling a particular material. Many metals, including tin, aluminum, copper, lead, zinc, nickel, and iron, are recycled because of their high economic value per unit weight or volume. Some of these metals have physical characteristics such as high density or magnetism which permit mechanical separation, while other metals have chemical characteristics such as ease of selective dissolution which facilitate chemical separation. The cost of separation and recovery by mechanical systems is usually lower than for chemical systems.(12) Further, ferrous materials are among the easiest to recover because iron and most steels (excluding certain grades of stainless steel) are ferromagnetic and can be routinely separated from non-magnetic materials using standard industrial drum or belt magnetic separators with either permanent magnets or electromagnets.(19)

A number of systems have been developed to process municipal solid waste in order to separate and recover the materials of interest. The principal unit operations for separating municipal ferrous scrap include: (a) incineration or mass-burning of the solid waste followed by magnetic separation of the ferrous residue from the ash; (b) front-end separation or shredding the solid waste followed by magnetic separation and/or air classification; and (c) wet pulping.(20)

Most facilities currently operating use either approach (a) or (b), although a single system combining shredding and the separation of the non-combustibles followed by mass burning to generate steam and/or electricity probably combines the best technical features of both systems.(11) Since each unit operation sequence affects the chemical and physical characteristics of the recovered ferrous scrap differently, the relationship between processing, contamination and market will vary.

Impediments to Increased Usage of Municipal Ferrous Scrap

There are a number of factors that promote the separation and recovery of municipal ferrous scrap from solid waste. These include: increasing domestic demand for old scrap due to the growth of electric furnace capacity and increased exports; generation of ferrous scrap as a by-product of burning municipal solid waste as a fuel; the relative ease of separating and recovering ferrous scrap from the other constituents in municipal solid waste; and pressure for increased recycling as part of an overall materials conservation effort. Yet, in spite of these inducements, significant growth in the demand for municipal ferrous scrap has not yet occurred. In fact, market consumption of municipal ferrous scrap has actually decreased since 1976.(21) At the end of 1979, there were 56 municipal resource recovery systems in operation, but only 27 were actually separating and recovering ferrous scrap.(13)

The obstacles to increased consumption of municipal ferrous scrap are usually divided into two categories, institutional and technical. Both of these barriers have an impact on the economics of recycling municipal ferrous scrap or cost of producing the scrap, while the elimination of only one barrier is a necessary but not sufficient condition for increased usage. Many institutional barriers to recycling MSW have been identified in recent years.(10,22,23). These include: the effect of depletion allowance taxes and severance taxes; the effect in the past of different transportation tariffs for virgin ores and secondary materials; ownership and control of the flow of municipal solid waste; public sector versus private sector ownership and operation of resource recovery facilities; and control of ferrous scrap exports. These and other institutional barriers will not be further discussed because often the obstacles are artificial or arbitrary and almost all contain significant questions of public policy. However, if these institutional obstacles were eliminated, technical barriers would remain which are equally important in limiting the demand for municipal ferrous scrap.

The technical barriers are primarily of two types: lack of national standards and specifications for the materials recovered from municipal solid waste(12); and true technological obstacles resulting from the impact of municipal ferrous scrap on processes using this material and the properties and quality of products made with the material. Lack of national material specifications and standard test methods for recovered materials place the producer of recovered products, such as a resource recovery facility, at a disadvantage with regard to identifying which of the potentially recoverable materials have real markets and which materials do not.

The primary technical obstacle limiting demand for scrap, and in particular municipal ferrous scrap, is the presence in the scrap of certain chemical impurities or residual elements, primarily tin, copper and aluminum, in amounts in excess of that found in either home or prompt industrial scrap or in primary metal produced from virgin ore. In the iron and steel industry and iron foundry industry, the levels of residual or tramp elements can seriously impair the properties of steel and cast iron products made with this scrap. In the detinning industry, copper precipitation industry and in iron and steel production, these residual elements can also disrupt the chemical processes themselves. In MFS, the tin originates primarily from tin-coated food and beverage cans while the aluminum contamination arises from the aluminum tops of bi-metal beverage cans. Copper is contributed by electrical components such as motors and wire although increased copper contamination occurs in the metallic residue of incinerators or mass-burning plants due to the vapor deposition of copper onto the residue.(14) Municipal ferrous scrap as produced by a single magnetic separation operation will almost always exhibit a high level of contamination not only by tramp elements but also by organic materials which have been carried along through attachment or association with the magnetic material. Although municipal ferrous scrap in this form can be used in each of the five major scrap consuming industries, these levels of contamination severely limit the amount of this scrap that can be used. For example, this MFS is limited in the iron and steel industry(12,24) and iron foundries(14), to about 10% of the respective furnace scrap charges.

Markets for Municipal Ferrous Scrap

If substantial growth in the domestic consumption of municipal ferrous scrap is to occur, it must take place in the iron and steel industry and the iron foundry industry which together currently account for about 97% of the total scrap consumed, as seen in Table 1.

Iron and Steel Production

Municipal ferrous scrap can be charged to either the blast furnace producing hot metal or to the BOF or electric-arc steelmaking furnaces. Charging municipal ferrous scrap as part of the electric furnace or BOF charge (without preheating) merely displaces another type of scrap and does not result in increased scrap consumption. Only if more steelmaking furnaces are built could scrap usage increase. True recycling can occur if municipal ferrous scrap is charged to the blast furnace because the scrap will displace iron ore, a virgin material. Increased scrap consumption would result even if overall iron and steel production did not increase. Studies have shown that the iron content in 32 kg of ore could be replaced by 23 kg of scrap.(25,26) In either case, however, the tramp elements tin and copper are not removed in either the blast furnace or the steel refining furnace. Although quantitative upper limits on copper and tin content for particular grades of steel are not always known, studies have shown that copper and tin increase susceptibility to surface melting or hot shortness during hot rolling operations and embrittlement at high temperatures, and decrease tensile ductility and toughness; all undesirable effects. Data reported for front-end separated scrap and incinerator residue, shown in Table 5, illustrates the magnitude of the problem.

Although the aluminum content of municipal ferrous scrap varies widely depending on the fraction of bi-metallic cans present, an upper limit of 2% can be estimated based on available data.(27) When this scrap is charged in a blast furnace, the aluminum will exothermically reduce some of the iron oxide from the ore charge to form alumina. The combination of increased temperature and alumina will decrease the life of the blast furnace lining. Using this scrap in a steelmaking furnace creates somewhat different problems. Here the aluminum reacts with the iron oxide in the slag and alters the slag chemistry. As the iron oxide content of the slag decreases, phosphorus reversion in the slag occurs and the phosphorus level in the steel increases, decreasing the formability of the steel.

Processing the waste can reduce the detrimental effects of these tramp elements. Shredding the solid waste followed by air classification will greatly reduce the organic contamination by removing most of the light paper and plastics(19), and if the ferrous fraction is then magnetically separated, the copper level will be greatly reduced(14) because the non-magnetic copper constituents are left behind. A second finer shredding and a second magnetic separation can reduce the aluminum by up to one third because many of the aluminum can tops become separated from the can bodies(30) and are left behind. Alternatively, heating the scrap to 600 F (315^{o}C) oxidizes the aluminum and reduces the aluminum level by 70%.(31) At this point the tin level can be reduced to the range 0.03% to 0.1%(32,33) by chemical detinning, producing a material which approaches the quality of No. 1 bundles.(34)

Iron Foundries

The tramp elements tin and aluminum and to a lesser extent copper also affect the properties and structure of the various cast irons produced, including gray cast iron, ductile cast iron, and malleable cast iron.(24,25) The aluminum concentration is sufficient to cause casting problems. Excessive slag formation can occur as the aluminum is oxidized to alumina; but, more importantly, the presence of as little as 0.02% aluminum increases the susceptibility to pinhole formation or porosity due to hydrogen absorption from the air or from moisture in the mold. In cast iron, tin levels above 0.04% completely stabilize the pearlitic microstructure and thus changes the properties. For ferritic ductile iron grades, the maximum tin level should be lower than 0.04% and for unannealed malleable cast iron, the upper limit is about 0.02%(28). Copper up to 0.5% reduces the ductility of ductile cast iron. Trial cupola heats using 10% of the charge as undetinned magnetically separated municipal ferrous scrap produced satisfactory gray cast iron automotive castings.(35) Although cast irons are more tolerant of some tramp elements than steel, processing operations similar to those identified for upgrading municipal ferrous scrap for iron and steel production would be needed to lower the tin and aluminum levels before significantly higher proportions of this scrap could be routinely used in foundries.

Ferroalloy Production

Ferroalloys, used as additions in the production of alloy steels, are made primarily in electric-arc furnaces. Municipal ferrous scrap has been used as part of the furnace charge for producing ferroalloys even though alloy steels often have greater limitations on tramp element levels than the carbon steels. Incinerator scrap is preferred because all of the organic contaminants have been eliminated, even though significant tin and copper impurities from the scrap ultimately end up in the alloy steel product. However, since the ferroalloy is typically only a small addition to the steelmaking furnace, the dilution of the tin and copper results in acceptable levels in the steel product.(28)

Detinning and Copper Precipitation

The detinning industry produces the only domestic supply of tin and uses clean tin-plate scrap as the source of tin. Municipal ferrous scrap with its high percentage of tin-coated food and beverage cans is another potential tin source. Bi-metallic cans with aluminum tops and possibly organic contaminants, however, pose severe problems in the commercial detinning process. The sodium hydroxide solution used to dissolve the tin will react with the aluminum to form sodium aluminate, thus consuming the detinning reagent. The sodium aluminate further causes an increased loss of solution when the detinned material is removed from the bath due to increased solution viscosity(24), and reduces the efficiency of the electrodeposition process which recovers the tin from the bath(12). Although aluminum contamination can be considered an economic problem as well as a technical obstacle, the impact is continuous, with no minimum threshold, and of magnitude directly proportional to the aluminum content.(31) The organic contaminants, including textiles and food residue retained in the cans, are retained in the sodium hydroxide solution and thus interfere with the optimum operation of the bath. Additional processing of municipal ferrous scrap, such as a second shredding and second magnetic separation or a chemical pre-treatment, is often necessary to reduce the aluminum and organic contamination to acceptable levels.

The primary requirement for municipal ferrous scrap use in the copper precipitation industry is a high surface area to volume ratio and a low level of organic contamination. Although detinned municipal ferrous scrap is more chemically reactive in the precipitation reaction than incinerated scrap where the tin is alloyed with the iron, both types of scrap are essentially free of organics and are used to recover copper. In 1974, almost 15% of the domestic copper production was produced by the precipitation process.(4) Further expansion of this market is uncertain because of a trend towards using ion-exchange techniques to recover the copper.(36)

Role of Standards

There is a consensus that the development and operation of resource recovery systems has been hindered by the absence of widely accepted national standards and specifications applicable to materials recovered from municipal solid waste.(12,37,38) The first codification of ferrous scrap specifications occurred in 1926.(39) These specifications and their modern successors are "origin specifications" which describe the source of the material and the limits of the major contaminants. Origin specifications are most successful when the materials are derived from established processes.(38) The principal focus in the past has been on industrial scrap and certain special categories of obsolete scrap such as railroad products and automobiles in which the scrap can be characterized using origin specifications.

There is a strong need for quantitative specifications for materials recovered from municipal solid waste. Although the value of recovered materials generally increases with purity and homogeneity, the key to the usefulness of these materials, and thus their potential for increased markets, is the ability to ensure a reproducible quality.(12) Often it is the uncertainty over impurity content that causes potential buyers of recycled materials to fall back and demand unnecessary higher levels of scrap quality. Acceptability of materials recovered from solid waste is the major problem. It is necessary to overcome the garbage syndrome--if it looks like garbage, feels like garbage, smells like garbage, then it must be garbage.

Recognition of this problem in 1974 led the American Society for Testing and Materials (ASTM) to create Committee E38 on Resource Recovery to bring together representatives of many diverse interests in this new field for the purpose of developing standards. An important goal of this process of developing consensus standards was to insure significant participation by all interested parties, especially the intended users of these standards, so that a strong incentive is created to apply the standards in the market place. Representatives of resource recovery facilities, Federal and state agencies, and industrial consumers of ferrous scrap, working in cooperation, have developed two national consensus standards for municipal ferrous scrap that have been formally adopted by ASTM: ASTM E701-80, Standard Methods of Test for Municipal Ferrous Scrap; and ASTM E702-79, Standard Specification for Municipal Ferrous Scrap.(40) The specification document defines the chemical and physical requirements for municipal ferrous scrap in the five market areas of copper precipitation, iron foundries, iron and steel production, detinning, and ferroalloys. Requirements for chemical composition, metallic yield, cleanliness as measured by combustibles content, and bulk density are listed where applicable. Footnotes giving processing hints and limitations have been added to provide supplementary information for those not experienced in the resource recovery business.

Trends

Present trends in steelmaking technology and ferrous scrap supply(9,41) could result in increased demand for scrap including municipal ferrous scrap. The reduced size of automobiles will eventually reduce the supply of automotive scrap while changes in materials used in automobiles may lower the resulting scrap quality. Anticipated growth in continuous casting capacity with its lower scrap generation than ingot casting, and improved electric furnace productivity will reduce the quantity of home scrap. Efforts by some steel fabricators to recycle their in-house scrap will reduce the availability of prompt industrial scrap. Finally, the continued growth of scrap-based electric-arc furnace capacity, combined with increasing overseas exports of scrap, will place added pressures on additional sources of scrap.

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Table 1. Total Ferrous Scrap Consumption by Industry

Industry	Year	Metric Tons Consumed	Reference
Iron & Steel Production	1978	66×10^6	(1)
Iron Foundries	1979	13.6×10^6	(2)
Ferroalloy	1973	0.45×10^6	(3)
Detinning	1974	0.64×10^6 (a)	(4)
Copper Precipitation	1974	0.45×10^6	(4)

(a) Based on 4.5 kg of tin per metric ton of tin-plate scrap

Table 2. Modern Steelmaking Processes

	Percent of U. S. Steel Production			
Year	Bessemer	Open-hearth	Electric-arc	BOF
1890[a]	86%	12%	0	0
1900	66%	34%	0	0
1907	50%	50%	<1%	0
1950	5%	89%	6%	0
1969	<1%	43%	14%	43%
1978	<1%	16%	24%	60%

(a) 2% produced by crucible process

References (1,5,6,7,8)

Table 3. Typical Composition of Municipal Solid Waste, By Weight

paper and paper products	30% to 34%
yard waste	20% to 21%
food waste	14% to 19%
plastics, textiles, rubber, wood	4% to 12%
glass	8% to 10%
metal	8% to 10%

References (11,12,14)

Table 4. Steel Production and Scrap Consumption in the U.S.

	Basic Oxygen Furnace (BOF)		Electric-Arc Furnace		Open-Hearth Furnace	
	Scrap Consumed	Steel Produced	Scrap Consumed	Steel Produced	Scrap Consumed	Steel Produced
Year			metric tons			
1978	23×10^6	77×10^6	32×10^6	30×10^6	11×10^6	20×10^6
1988 (Projected)	26×10^6	97×10^6	49×10^6	46×10^6	------	------

Reference (1)

Table 5. Tramp Element Levels in Municipal Ferrous Scrap

Tramp Element	Typical Tolerance Limit,[a] max	Municipal Ferrous Scrap Front-End Separated	Municipal Ferrous Scrap Incinerator Residue[b]
Tin	0.03	0.5[b]	0.18
Copper	0.01	0.21[c]	0.62

(a) Reference (27)

(b) Reference (28)

(c) Reference (29)

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11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

The secondary metals industry associated with the recycling of ferrous scrap is tied to the development in the 1850's of the acid-Bessemer furnace, the first large capacity steelmaking process. Within twenty-five years of this development, the recycling of ferrous scrap became an established industry. Changes in steelmaking technology since World War II, especially since the 1960's, are impacting the traditional ferrous scrap industry. The increased demand for old scrap is due to growth in electric-arc furnace steelmaking capacity, reduced availability of home scrap and prompt industrial scrap, and larger scrap exports. Ferrous scrap recovered from municipal solid waste is one of the new sources of old scrap that may satisfy these increased demands. Systems for the recovery of the ferrous fraction from municipal solid waste have been developed, although increased usage of municipal ferrous scrap has been very slow due to institutional and technical barriers. The technical barriers posed by the physical and chemical characteristics of municipal ferrous scrap strongly inhibit the development of markets for this new material. The real and potential markets for increased consumption of municipal ferrous scrap are discussed in terms of these barriers together with the important role of standards for municipal ferrous scrap in improving communications between buyers and sellers.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

Ferrous scrap; iron; municipal ferrous scrap; municipal solid waste; recycling resource recovery; standards; steel

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