How changes in scrap mix affect Consteel charging of an EAF

A description of the various types of scrap available to the EAF operator and how these affect the performance of a Consteel continuous charging and scrap preheating system are described. By F Memoli*, J AT Jones*, & F Picciolo**

THE Consteel® charged EAF is a very flexible process that can adopt a wide range of scrap mixes in the metallic charge. More than 40 plants are currently operating Consteel technology, producing any kind of steel grades, from rebar to stainless steel. They are using different types of scrap mixes for their purposes.

Consteel combines preheating the scrap charge with continuous charging by directing the off-gas from the EAF through a tunnel through which the scrap is slowly conveyed and charged continuously to the furnace via a side wall port.

Due to scrap availability country by country, region by region, the Consteel process has to adapt the melting operation to provide the EAF with the most cost-effective result. In fact Consteel units around the world adopt scrap mixes with many types of scrap grades: from the common shredded, through HMS#1, HMS#2, plate and structural, Busheling, Bundles, to the less common machine shop turnings, shoveling turnings, heavy turnings, clippings, punchings, HBI, Pig Iron, chargeable ingots and ingot butts, foundry steel, hard steel, cast steel, billets, blooms, ladle skull, tundish skull and hot metal. The size of scrap used varies from less than an inch to over five feet maximum dimension, as a result of that, the scrap mix density has a very wide range.

This work discusses scrap mix data collected in some Consteel plants currently operating worldwide, and how different scrap grades affect the operation, consumption and the quality of liquid steel, whether for rebar or stainless steel, and grades between.

**Bucket charging**

Scrap selection plays an important role in any EAF operations. The characteristics of scrap – as density, metallic Fe content, gangue content, oil, grease and non-metallic content – have important impacts on the process.

In a bucket charged EAF, scrap density affects the number of charges required to produce a heat but also impacts the electrical and chemical energy profiles. Dense scrap can be slower to melt and if aggressive burner and oxygen lancing profiles are employed, dense scrap may deflect the jet back onto the furnace walls resulting in damage. If large quantities of dense scrap are charged, it may be necessary to operate at lower arc voltage and higher current during refining in order to ensure that the dense material is fully melted prior to tapping.

Non-metallic content in scrap leads to dust generation in the furnace and increased slag volume. Gangue also leads to increased slag volume and increases the requirement for calcite and dolomitic lime additions. In addition, since fluxes are typically added in the buckets, the slag chemistry will vary throughout the melting of the charge.

Oil, grease and combustible content in the scrap results in higher energy content in the off-gas stream and, in some cases, will result in higher VOC content in the off-gas if they are not fully combusted. Metallic yield has an important effect on specific energy and raw material consumption. Thus, it is important to ensure that chemical energy inputs along with carbon inputs are balanced to reduce losses of iron units to the slag.

Layering scrap in the bucket has been demonstrated to have significant effects on melting dynamics, thus affecting energy consumption. The scrap profile determines electrical and chemical energy efficiency. An optimal scrap profile in the bucket affects energy consumption by as much as 20 kWh/t. In addition, every time the furnace roof is opened to charge scrap, about 10 kWh/t of energy is lost due to radiating heat.

**Consteel charging**

The Consteel furnace is by its nature both different and similar to a conventional EAF. The Consteel process is continuous, so scrap density does not affect the number of charges as the scrap is continuously fed into the EAF through the side of the furnace. A good Consteel operation is achieved matching energy input to scrap feed-rate. In the early days, that was achieved by manual control of the scrap feed-rate into the furnace. Nowadays this operation is fully automated, thanks to the weighing systems on the EAF shell, which provides real time liquid steel weight in the furnace. The key to maximum throughput in the Consteel is to contain the arc in the slag, leading to maximum arc stability and maximum and stable active power.

Being a continuous process, the best practice for scrap charge is always to keep as near constant as possible the layer of scrap, in size (height) and grade (mix), in order to have a smooth flow of scrap into the EAF. This concept will be described further in the article.

Non-metallic components in the scrap will report to the dust in the off-gas. The Consteel process typically generates about a third less dust than a conventional bucket charged EAF. The heavier dust is captured in the incoming scrap and is recycled to the furnace.

The high yield in the Consteel process benefits from its design. Fluxes, chemical energy inputs and carbon inputs – whether in the metallic charge, through injection into the EAF or other – must be properly balanced to maximize yield. Consteel operates without any highly oxidizing burner flame and the constant flat bath in the EAF helps keep the FeO oxidizing/reducing reactions within the slag itself, so that the proper carbon balancing in the slag can lead to iron recovery and maximise metallic yield.

**Consteel installations**

The total number of Consteel plants to date is 45, installed in the United States, China, Italy, Japan, Germany, Greece, Russia, Brazil, Ecuador, South Africa, Morocco, Thailand, Vietnam and South Korea. In addition, three further plants are under commissioning or installation located in Canada, Mexico and Egypt. The very first Consteel was in Charlotte, North Carolina, USA and started up in 1989 and is still in operation.

Today worldwide installed capacity is over 40Mt of liquid steel per year, more than a quarter have been installed in the past three years, which demonstrates the success and acceptance of the technology as a reliable and dependent alternative to the conventional bucket charge EAF (Fig 1).

Consteel installations are characterised by a relatively low installed active power factor which increases with heat size (Fig 2). The correlation factor between the two parameters is very high. The data reported in Fig 2 is relevant to the existing installations and show the Active
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Power used in a Consteel being on average 0.53 times the heat size of liquid steel. That is a remarkable correlation, considering the significant difference between the various installations in terms of steel grade (from rebar to stainless steel) and scrap mixes. This is perhaps the most important design difference between a Consteel and a conventional EAF. In Ultra High Power electric arc furnaces bucket charged the relationship between active power and heat size can be as high 1:1. In contrast, Consteel reduces the ratio to 0.5:1.

In an analysis conducted in 2011, relevant to the importance of the size of the hot heel in a Consteel EAF, it was demonstrated that for those units that keep over 46.5% of metal in the hot heel, productivity is over 2t/h.

Scrap grades charged
There are often two main questions regarding the scrap charge to a Consteel EAF.
- What are the scrap grades that can be charged in a Consteel? and
- What is the maximum dimension of scrap that can be charged to a Consteel?

To the question on scrap grades, the answer is any type of commercial grade of scrap, all internal recycled scrap and generally all the other types of metallic raw materials that can be charged into a conventional EAF. In terms of scrap grades there are absolutely no limitations to the Consteel charge. Even the smallest Consteel in operation today can charge any commercial scrap grade and dimension.

To answer the second question, regarding scrap dimension, the sole rule to be taken into account is the distance between the Consteel pan and the electrodes, as shown in Fig 4.

For the Consteel process, thanks to its higher amount of hot heel, it is easier to melt larger pieces of scrap than in a conventional EAF of the same size. The right use of the hot heel combined with good bottom stirring, is one of the keys of the performance of Consteel plants.

Having addressed these main two questions, there follows a list of scrap grades most commonly used in Consteel plants. These are in no way different to the scrap grades normally charged in any conventional bucket charged EAF. The codes indicated are relevant to the latest scrap specification published in the guidelines of Ferrous Scrap by ISRI(1).

**Heavy melting steel (HMS)**
- No 1 HMS Steel scrap ¼ inch and over in thickness. Code 200, 201 and 202, individual pieces not over 60 x 24 inches (Fig 5).
- No 2 HMS Steel scrap, black and galvanized, 1/8 inch and over in thickness, Code 203, 204, 205 and 206, size over 60 x 18 inches.

Fig 6 shows HMS1 and HMS2 charged on a Consteel conveyor on a regular basis. This illustrates that it is possible to charge the Consteel conveyor with large pieces of scrap. In fact, the width of the conveyor in Fig 6 is over 6 feet (1829mm) and some scrap pieces are almost as long as the width of the conveyor. These are defined as oversized where specified by the ISRI codes 200-202.

The preferred way to charge HMS scrap in a mix of scrap types on a Consteel is on the top layer as this type of scrap of relatively high density and can be heated by the off-gasses coming out of the EAF more effectively. By positioning the HMS as a top layer, it will be directly exposed to the stream of gasses and heat will be
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transferred to the scrap by radiation and also by convection, enhancing the heating effect. In tests conducted in a Consteel installation several years ago, the temperature that can be reached is up to 800ºC on average on the top layer.

Moreover, this type of scrap is not creating a physical barrier to the heating gas so heat can penetrate to the bottom layers of lighter scrap, producing an additional heating effect.

**Busheling**

Code 207, Clean steel scrap, up to 12 inches (250mm) in any dimensions, including new factory busheling.

Bushelings work in a Consteel in almost the opposite way to HMS. They are low density and not so easy to heat by the off-gasses. In several analysis tests and campaigns, it has been demonstrated that positioning busheling as a top layer on the Consteel charge conveyor creates a barrier layer against heat penetrating to the scrap beneath. Busheling tend to reflect the heat. Thus, this scrap must be charged on the bottom of the conveyor and should be covered with other types of scrap such as HMS or shredded (Fig 7).

The low density of busheling is not an issue provided it is correctly positioned and it is currently being charged at several Consteel plants, in particular those producing high quality steel grades. Busheling and also even lower density scrap such as turnings, can make up 50% of the charge.

**Bundles**

Code 208 and 209, No1 bundles weighing not less than 75lb/ft³ (1201kg/m³)

While a bundle is a cleaner metallic scrap, it is more difficult to melt, being less porous and more compact than heavy scrap or bushlings (Fig 8a & b). Whether to use it or not does not depend on the EAF charge method, it is more a decision relevant to the scrap quality mix, the steel grades to be produced and so on. Some Consteel plants are charging high percentages of bundles for that reason.

In a Consteel conveyor, bundles are charged by positioning pieces at a certain distance from each other, so that when they arrive into the furnace and are submerged into the hot heel they melt quickly by convection in the liquid steel.

A general understanding is that large bundles may constitute a problem and small bundles are preferred, as problems with big bundles are well-documented as: blow-back of oxygen if a bundle should fall in front of a burner (but that can happen for any type of large plate scrap); poor melting efficiency (smaller scrap pieces are always better than large scrap pieces, in particular when there is not enough hot heel); and the risk of breaking an electrode when a bundle caves in on an electrode.

Most melt shops try to minimise the use of large bundles by using busheling and alternative iron units (pig iron, DRI, HBI) to achieve the desired residual levels in the steel.

For a moderately large conventional EAF – something between 100 and 200t heat size – running a steel mix aiming for 0.12% Cu or lower as a residual element, especially on a single bucket charge furnace, the problem is mainly related to scrap density. To achieve such copper levels, many bundles have to be used if pig or other scrap substitute are not charged. It is then not possible to charge all busheling because of the large volume these occupy. But using bundles can create cave-ins. The regular bundle size is 3ft x 2ft x 2ft, (90cm x 60cm x 60cm) but these are getting harder to find as many balers in the US now make 2.7ft x 2.7ft variable 3-4ft (81cm x 81cm x 90-120cm).
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Using a larger bundle size may, however, increase power requirements and incidents of electrode breakages. This is where Consteel comes in to help: bundles can be placed on the charge conveyor in the desired amount and travel to the EAF without major issues of causing electrode breakages. At the same time, busheling – which are generally more affordable than bundles – can be charged as well without any problem, since low density in the scrap mix is corrected by the Consteel technology by means of adjusting the speed of scrap on the conveyor.

**Shredded scrap and clippings**

Shredded scrap (Code 210 and 211) has an average density of 50 to 70 pounds per cubic foot (800–1121 kg/m³) and Code 212 has an average density of 60 pounds per cubic foot (961 kg/m³) (Fig 9).

Shredded scrap is the scrap grade generally considered very easy to charge in both a Consteel and in the conventional bucket charge EAF. Similar to heavy melting scrap, shredded is a type of scrap that is easier to heat with off gasses as the heat of the off gas from the EAF can permeate the charge on the conveyor and reach the bottom layers of the scrap, enhancing the heating effect of the Consteel heating tunnel. Shredded is charged on a Consteel by means of standard crane magnets or grapples, and more recently it is also charged directly by belt conveyor, as happens, for example, in some Consteel installations in North and South Carolina and elsewhere.

Shredded is indeed a type of scrap that fits the charging mode of a Consteel very well. It can be accommodated in the charge conveyor (as it accommodates itself in any bucket) filling gaps and creating a continuous layer of metallic charge. The crane operator can use shredded to complete the charge of previously charged scrap of different type or can use shredded alone, filling the conveyor to the target charging height.

As can be appreciated in Fig 10, for this study some specific data has been collected to determine the correlation between the percentage of shredded scrap and total energy consumption (electrical + chemical – mainly decarburisation reactions happening in the liquid steel during supersonic oxygen injection).

The data has been collected from a group of similar N American steel plants below 100t heat capacities and all producing similar steel grades, mostly rebar, in three-phase AC furnaces.

The data reported in Fig 10 represent averages from long campaigns from one month to six months, so the number of heats that have been analysed is in the range of several thousands.

This correlation, even if not reaching values that can lead to a definitive conclusions, is still high for the steel industry. Nevertheless, it should be always remembered that a correlation does not imply causation.

The reality is that cause and effect can be indirect, or due to confounding variables, and so the assumption of causation is false when the only evidence available is a simple correlation. Thus the fact that a higher percentage of scrap indicates a lower total consumption of energy should not be directly interpreted as a cause.

The trend indicated in the graph shows that for every percentage point of shredded scrap in the mix from 0% to 20% there is a decrease of total energy consumption of between 0.15% to 0.20%, and when the shredded percentage increases from 20% to 40% the decrease of electrical energy is less pronounced at 0.10% to 0.15%. At over 40%, for every additional percentage point of shredded in the mix, the decrease of energy consumption is only 0.05%.

So even if the correlation indicates that increasing the shredded in the mix provides a certain benefit in terms of energy consumption, the effects are not so dramatic to indicate that shredded should be the preferred scrap grade to be used in a Consteel. On the contrary, it is well understood that for some steel grades, considering the amount of undesired residuals in shredded, its percentage in the mix should be limited, as happens for any EAF.

**Punching and plate scrap**

Code 234, punching or stampings, plate scrap, and bar crops is material cut to 12 inches (30 cm) and shorter and at least 1/8 inch in thickness or punching or stampings under 6 inches (15 cm) in diameter and any gauge (Fig 11).

This material in the Consteel has a behaviour in the middle between busheling and HMS. Depending on the thickness and the density, it may heat up readily in the Consteel tunnel, but if the plate covers scrap beneath, it will create a protective layer. So it should always be used in the middle or bottom of the conveyor.

**Turnings**

Code 219 and 220, machine shop turnings, Code 245, shoveling turnings; Code 247, alloy free turnings. Code 251, short, heavy steel turnings (Fig 12).
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The use of turnings in electric steelmaking has always been very limited, due to the very low density of this type of scrap and the issues arising from the high content of oil and other flammable components that create difficulties with bucket charge. With the introduction of Consteel technology, such issues have been resolved.

A very important matter is avoiding turnings being exposed to the hot gasses in Consteel as turnings tend to melt if directly in the stream of the hot flue gases, and melting can block the flow of scrap in the tunnel. So turnings must be charged on the bottom of the conveyor, then covered with other scrap. Turnings will then proceed steadily throughout the heating tunnel, increasing in temperature by conduction from scrap heated above, until the turnings enter the liquid heel in the EAF where they melt rapidly due to their very large surface area.

In test campaigns carried out in Italy, entire sequences of heats were conducted with over 50% of turnings in the charge with no issue on the heating operation, nor tap to tap time. In fact the low density is not a problem for the Consteel. The lower is the density the faster will be the charging speed. In fact scrap can travel up to 8m/min on the conveyor, and depending on the conveyor cross section, the flow rate of scrap into the furnace will always meet the EAF productivity requirements.

It is well noted that a high percentages of turnings are not suitable for all steel grades. From a cost standpoint, it is recommended to increase as much as possible the percentage of turnings, as these are a very inexpensive scrap source and so permit the plant to reduce its average cost for metallic raw materials.

Pig Iron

The main purpose of charging pig iron in the EAF is to dilute the residuals contained in the regular scrap to the target requested by the steel grade to be produced.

In addition to that, the pig iron provides more chemical energy thanks to its high carbon and silicon content, as well as keeping a higher level of tapped carbon. Thanks to its high density (approx 3.6t/m³) it allows a decrease in the total scrap charge with possible benefits in terms of filling the EAF and reducing the number of buckets per heat (Fig 13).

Due to its high carbon content and high density the amount of pig iron that can be charged into a conventional EAF’s should be well balanced taking into account the effects of its high density on the electrical energy transfer efficiency and the maximum obtainable decarburisation rate.

Stainless Ni-pig

A Consteel unit that produces more than 800k/y of stainless steel (304-series), charges its 60t furnace with 100% Nickel-pig iron, a raw material with the physical characteristics of the regular pig iron plus a high content of nickel (up to 14%), as shown in Fig 14. Thanks to this metallic charge, the conversion costs are significantly lower than when using stainless steel scrap, especially in those countries where the availability of the stainless scrap is limited. Such a dense charge mix completely without scrap cannot be handled by conventional EAFs, both regarding electrical energy transfer and refractory related issues, as well as due to decarburisation constraints.

Another example of a high amount of pig iron charge in a Consteel is the case of Vallourec & Sumitomo Tubos do Brasil (VSB) that has been designed with a nominal scrap mix that has about 40% of pig iron.

Other scrap and raw materials

Other types of scrap generally charged on a Consteel conveyor include:
- Plate and structural steel;
- Internal returns such as billet crops, bloom and forge crops, axle, slab, heavy plate and heavy forge crops;
- Bar crops and plate scrap, forgings, bits, jars, tool joints;
- Steel castings, chargeable ingots and ingot butts, foundry steel;
- Hard steel cut, automotive steel consisting of rear ends, crankshafts, drive shafts, front axles, springs, gears.

Optimised scrap charge

Considering what has been said for each main scrap category, a few simple guidelines can be indicated to optimise the charge of scrap onto the Consteel conveyor.

There are charging rules also for the conventional bucket charge EAF, but these are definitely different from those that will optimise the Consteel process in terms of heating efficiency and in terms of the melting process.

The ‘3-D’ guideline

Scrap materials can be categorised following three main parameters’ density, dimensions and dirtiness:
- Density: the less dense the scrap is, the more readily will it increase its temperature in the heating tunnel, so very light scrap is generally charged on the lower layers of the conveyor, with high density scrap on top, to achieve direct heat radiation and convection from the hot gasses. This will avoid melting the light scrap on the conveyor and will enhance the heating effect and the average temperature of the scrap on the conveyor.
- Dimension: as for the density, also dimension plays a role in the heating time for a piece of scrap. Large pieces of scrap tend to heat-up more slowly than small pieces, and that is why large pieces of scrap (which are also usually more dense) are placed in the top layers of the conveyor, while small pieces would be on the bottom. This general consideration though has to be seen in connection with the other major guideline of ‘evenness’ for scrap height on the conveyor, as described below.
- Dirtiness/Cleanliness: clean scrap, bushelings for instance, produces a ‘mirror’ effect on heating, deflecting light/radiation and create a protective layer of scrap against heat transfer. The dirtier the scrap, the better it is for heating. So
dirty scrap tends to be positioned on the top layers of the conveyor.

Hence, considering the three axis diagram in Fig 15, the centre of the axis will define a type of scrap of low density, small dimension and very clean (turning, busheling). The more the scrap to charge is close to the centre of the axis, the deeper it should be on a Consteel conveyor.

**Evenness for scrap height**

A guideline of the same importance, if not more so, is relevant to how even and constant the top layer of scrap is on the charge conveyor. Maintaining a constant scrap height on the charge conveyor permits the automation process to perform at its best.

An EAF equipped with Consteel always sits on load cells that read the weight of the liquid steel inside the furnace in real time. One of the standard methods of operation of the Consteel foresees the calculation of the specific energy consumption in real time, by dividing the total energy input and the actual weight.

The level 2 control indicates to the furnace automation the correct profile of specific energy consumption that the furnace should have at each moment of the melting process, in order to optimise the steel temperature and more importantly the slag conditions, which are crucial to ensure the arc is covered to protect the refractories and maximise the active power and power factor.

Changes in density on the Consteel conveyor will produce variations in the real-time specific energy consumption calculated, and the automation will then change the conveyor speed accordingly to maintain the target value of specific consumption.

By its nature the Consteel process is a continuous process and the steadier are the operational parameters (electrical energy input, oxygen flow, charging rate), the better will be the result of the heat.

Variations of scrap density on the conveyor happen because of two factors: changes in the density of the scrap and potential uneven charge of scrap along the conveyor – scrap charged leaving holes in between, or ‘waves’ of higher piles of scrap.

Scrap charge methodology is as important in Consteel as much as it is in a bucket charge, so in order to reduce the variations of density and to achieve better operational results, plants using Consteel instruct their crane operators to charge the conveyor evenly. The typical type of scrap that is used to ‘fill the gaps’ is shredded.

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**References**

3 Scrap Specifications Circular 2013, Institute of Scrap Recycling Industries Inc (ISRI), 2012, pp 16-18
4 [web URL](http://rationalwiki.org/wiki/Correlation_does_not_imply_causation)