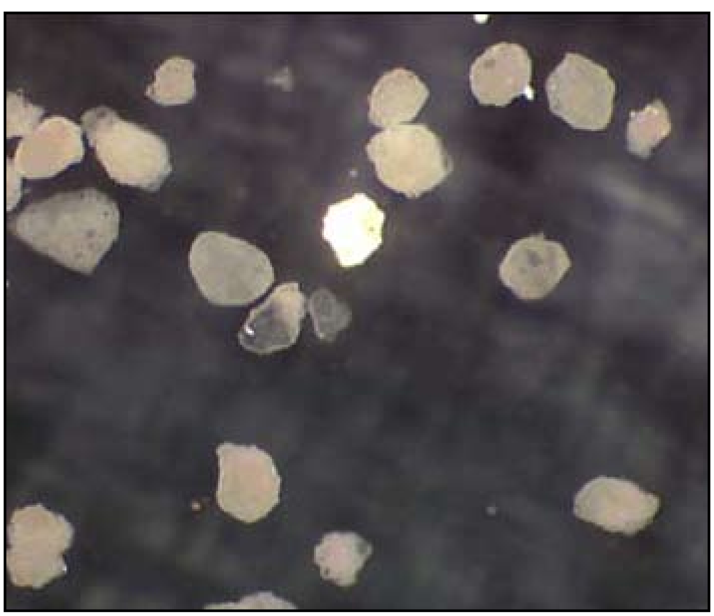
CLEMEX intelligent microscopy

Application note

Slag Particles
Image Analysis by microscopy

Smelting, or chemical reduction, is the process of heating an ore with a reducing agent, mainly carbon in the form of charcoal or coke, and purifying agents to separate the molten metal from the waste products. Nothing is known about the origins of smelting.

Dumping slag in fusion



A typical field of view with all three phases before analysis

The transformation of ores into purified metals started in what is now Turkey. The earliest known products of smelting date back to 6500 BC, and are in the form of cast lead beads. Copper, which has a melting temperature much higher than the 200 C of campfires, was used by 5000 BC. As for bronze, which is a copper/arsenic or copper/tin alloy, the earliest artifacts date from 4200 BC. Iron artifacts show that the intentional reduction of iron metal started around 1600 BC.

In nature, the ores of metals are often found oxidized and mixed in with silicates of other metals. Exposed to high temperatures during smelting, impurities separate from the molten metal and are removed. These impurities are called slag. Ferrous and non-ferrous smelting processes produce different slag and, depending on the reducing or purifying agents used in smelting, the byproducts will have various chemical compositions. Some resemble small rocks, others are granulated. Ground granulated blast furnace slag is obtained by quenching molten iron slag in water or steam to produce a glassy, granular product that is then dried and ground into a fine powder.

Commercially, slag has many uses. It has been used as road building material since the Roman Empire, 2000 years ago; it was used as ship ballast in the 16th and 17th century; and now has a variety of uses, from railroad track ballast to fertilizers, even as seawalls in order to arrest the movement of waves. Granulated slag is often reprocessed to separate any other metals that it may contain, and is used in concrete, in combination with Portland cement.

For this analysis, a sample of fine, purified slag particles intended for cement was tested to determine its quality, based on the size and transparency of the particles.

Analysis

An optical transmission microscope at a magnification of 100x, using cross-polarized light, is used to give the best distinction possible between the three types of features, as in Figure 1. A total of twenty images processed in series are used, the particles kept in focus using Linear focusing. The selected magnification is a compromise between resolution and focusing difficulties due to differing particle sizes.

After being captured from the video input, the images are copied to a temporary location, ensuring that the unmodified images are available for further processing. The Kirsch edge-detection algorithm is used to outline the slag particles from the background of the slide, as in Figure 2. The particles are binarized, after which the original image is restored and overlaid with the new bitplane (binary plane). Only those regions within the bitplane are of interest in the analysis.

Having now isolated all the particles from their surroundings, it becomes necessary to further separate them by type: crystalline (purple), glass (yellow) or milky (green). First, the glass particles are separated using a Gray thresholding operation. The crystalline particles are isolated using two thresholding operations: a Gray thresholding for the very bright particles, and a Color thresholding for the gold-colored ones, with the resulting area combined into one bitplane. The result of these operations is shown in Figure 3.

The resulting percentage area of glass, milky and crystalline phases as compared to the total area of the particles is measured using Area measures (Figure 4).

Results Summary

Phase Color	Percentage (%)
Glass Yellow	14.9
Crystalline Purple	2.6
Milky Green	82.5

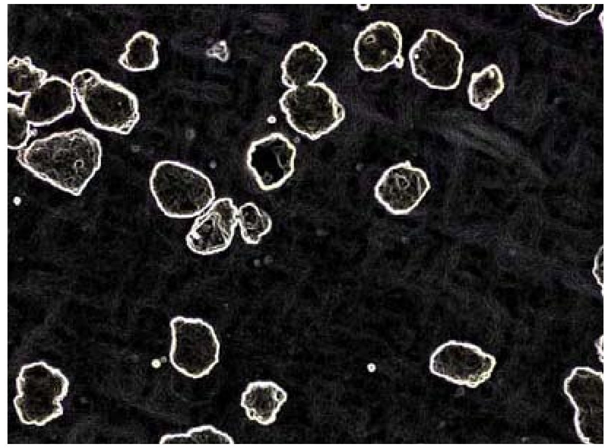


Figure 2: The same field as Figure 1, after edge detection using the Kirsch algorithm.

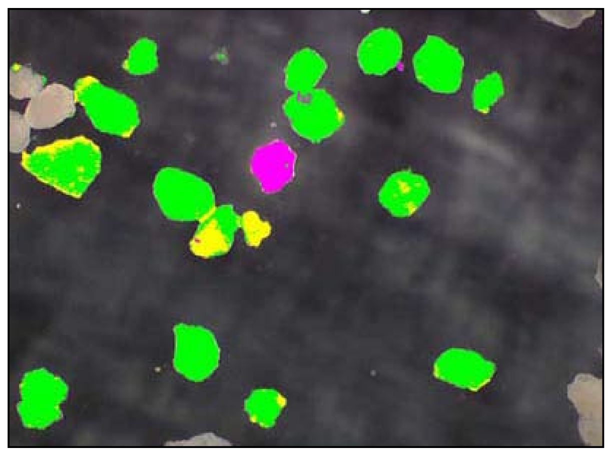


Figure 3: The same image as Figure 1, overlaid with the three particle types as detected by the system: yellow: glass; purple: crystalline; green: milky.

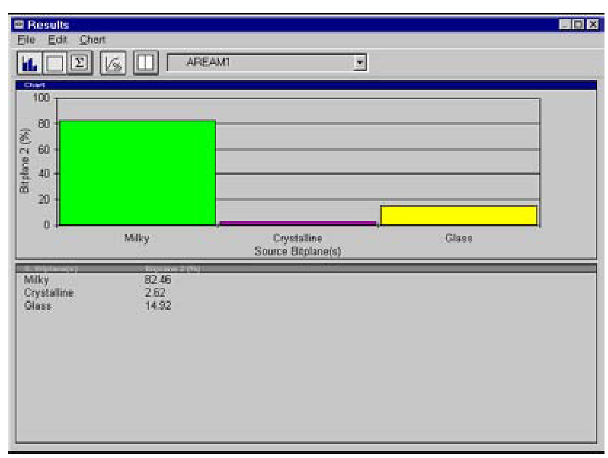


Figure 4: The results window from the Clemex Vision PE software, showing the percentages of all three phases, both graphically and numerically.