Mold Construction for Visualization of Solidification of Transparent Alloys

By: Mousa Alshehri, Naif Alzhrani, Nawaf Alhrbi, Abdulaziz Alnader (GP: Spring2019)

Supervised By: Dr. Mahmoud Ahmadein

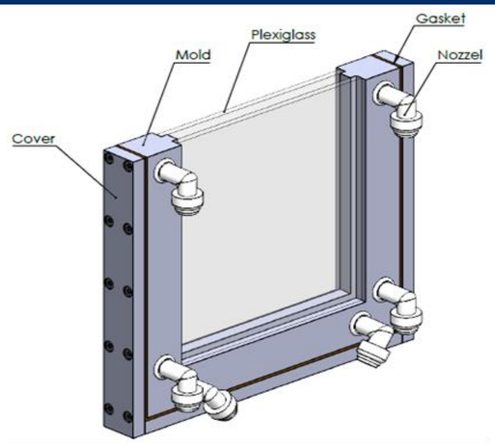
Al Imam Mohammed Ibn Saud Islamic University, College of Engineering, Mechanical Engineering Department

Motivation

Solidification process is very crucial to the properties of castings and other metallic products. During solidification several types of cast structures may form. In addition, some related inhomogeneities in composition (segregation) and porosity defects may arise causing undesired performance of the cast parts.

Control of solidification structure and defects formation requires very good understanding of the origin of their development. Therefore, observing solidification is aimed in the current work. Since metals are opaque and have high freezing point, they are replaced with the transparent NH_4Cl-H_2O system.

Mold Construction

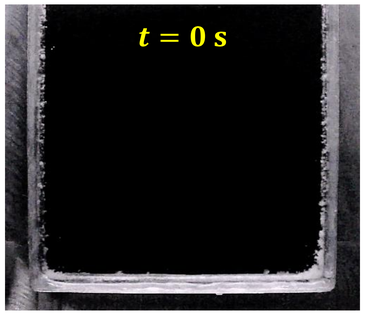


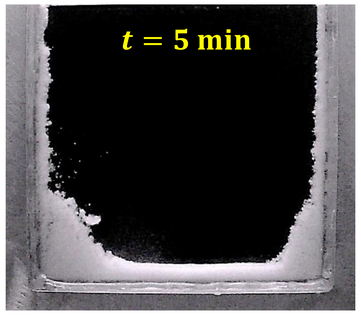
An aluminum metal mold (Alumic89) that consists of two side and one bottom wall. Each can be cooled separately via pumping of a cooling fluid at subzero temperature. It is provided with front and back transparent windows to allow observing and capturing the development of the solidification structure and the related phenomena.

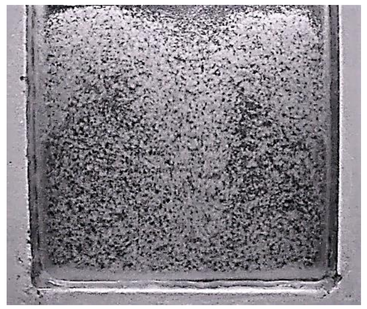
Experimental Work

i) Solidification Progress

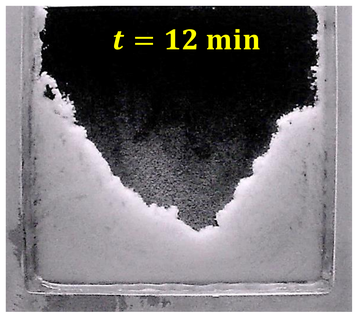
It is aimed here to follow the development of solidification structure by filling the mold initially with superheated ammonium chloride-water solution ($40\,℃$). Then, the mold is continuously cooled to near the eutectic temperature. The temperature is controlled via thermocouples connected to a digital meter. As shown below, solidification starts at the mold walls ($t = 0\,\mathrm{s}$) by nucleation of the columnar grains that grow opposite to heat flow direction.

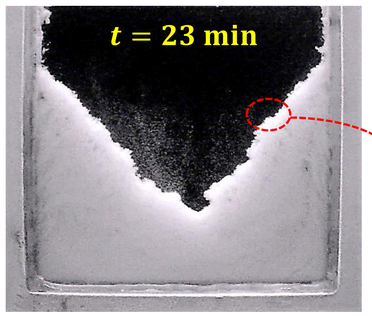






Pouring solution at 32 ℃ in an empty cold mold





Grains continue to grow dendritically (5 min). However, as time proceeds an intensive thermal- and solutal-driven convective flow ahead of the growing dendrites causing the destruction and fragmentation of their arms.

Fragments grow afterwards as equiaxed crystals. Also new equiaxed crystals nucleate from the liquid as a result of decreasing temperature gradient. The equiaxed crystals yields to gravity and is collected at the bottom of the mold.

ii) Effect of Pouring Temperature

The effect of pouring temperature on solidification structure was investigated by pouring a little superheated solution at $32\,℃$ with constant flow rate of ~13 cm^3/s. This leads to nucleation of equiaxed crystals during mold filling operation. Finally, an equiaxed structure was formed.

Observed Phenomena

Equiaxed and columnar grain formation – Dendrite fragmentation – Channels (freckles) formation that leads to macro-segregation).

Conclusion

An apparatus to observe the solidification process with controllable temperature was successfully constructed

Solidification starts initially at walls as columnar that grows perpendicular to mold walls in an opposite direction to heat flow.

Equiaxed crystals appears in the vicinity of the advancing solid front due to the mechanical fragmentation caused by the convective melt flow.

Pouring temperature of the solution showed a significant effect on the solidification structure. No crystals form during pouring at high temperature. But pouring with low superheat encourages the nucleation of equiaxed crystals.

Channels of solute rich liquid are formed within the solid/liquid much. This needs further investigation in the outlook.

References

1. F.C. Campbell, Fundamentals of Solidification, ASM International, (2012).
2. Eivind Strand Dahle, Grain Refinement of High Alloyed Steel with Cerium Addition, Norwegian University of Science and Technology (NTNU), (2011).
3. Davtzing and Rappaz, Solidification, CRC Press and EPEL Press, Italy, (2009).
4. J.Mojeritsch et rl, Experimental observation of convection during solidification of transparent alloys, Material Science Form, VOL.508, PP.157-162, (2006).