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Improving your investment casting process

„Part 1“: Porosity

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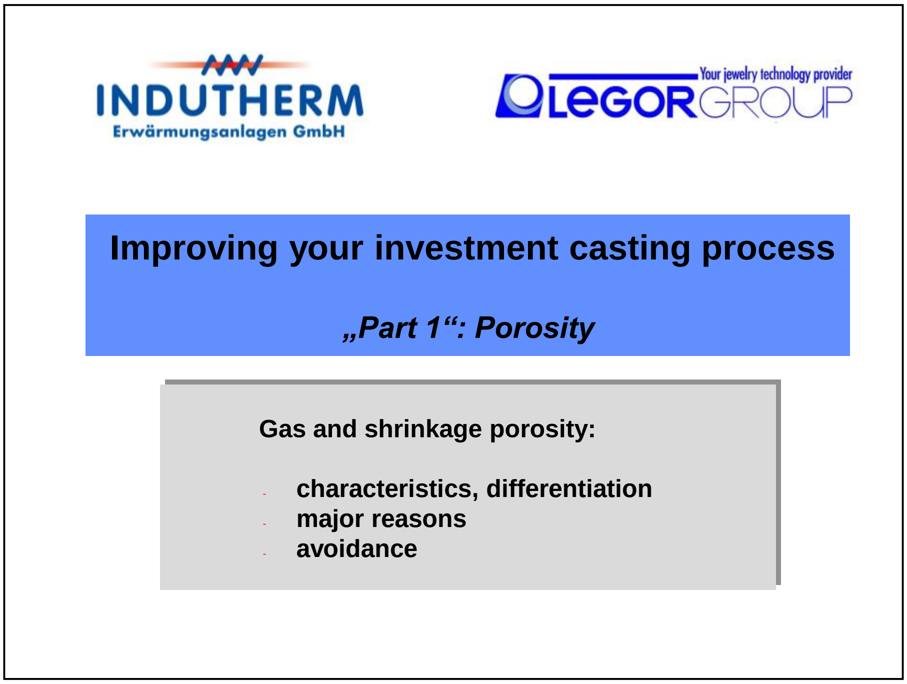

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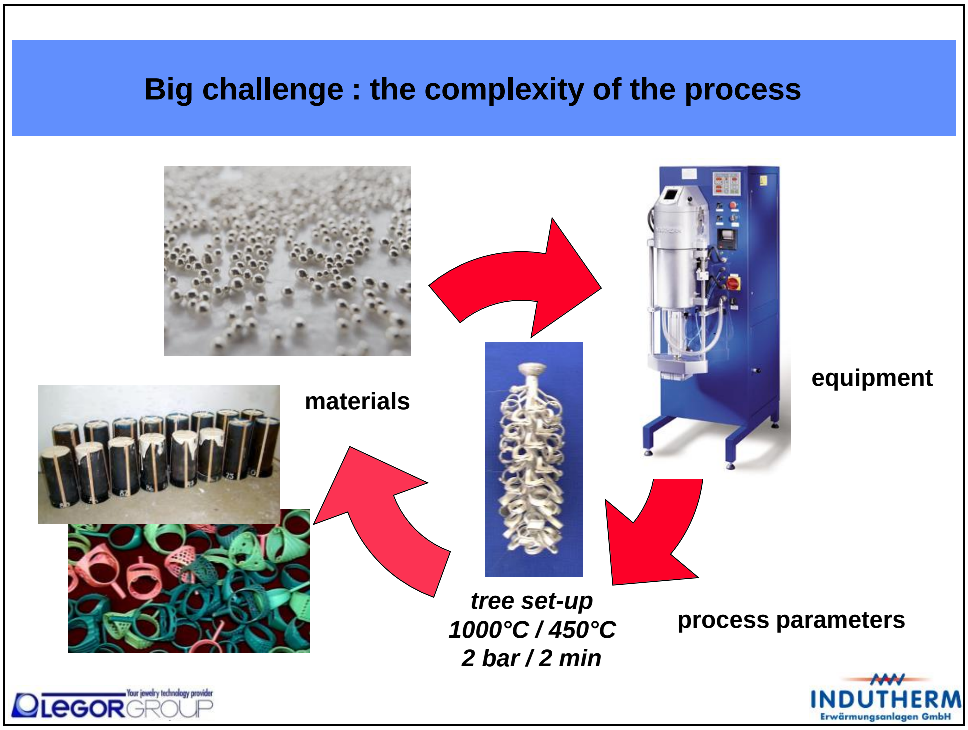
Improving your investment casting process

„Part 1“: Porosity

Gas and shrinkage porosity:

- characteristics, differentiation
- major reasons
- avoidance



Big challenge : the complexity of the process

materials

equipment

tree set-up
1000°C / 450°C
2 bar / 2 min

process parameters

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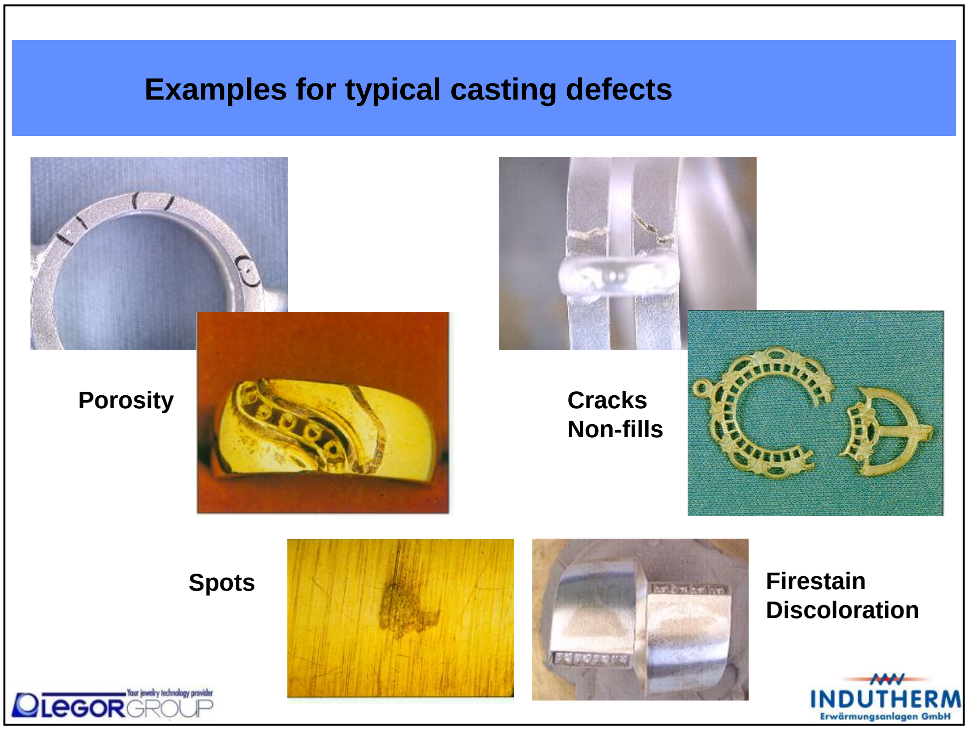
Investment casting is an incredibly complex process, with a lot of interrelations between the process parameters, the alloys, equipment and other materials used (like wax and investment). During the casting process all these factors interact in a complex way within few seconds or minutes.

In the seminar today we will talk mainly about process parameters for a particular combination of equipment and alloy. Remember that it is very important to have a constantly good and efficient communication with your suppliers so that an as good as possible support for your production is available.



Examples for typical casting defects

Porosity

Cracks
Non-fills

Spots

Firestain
Discoloration

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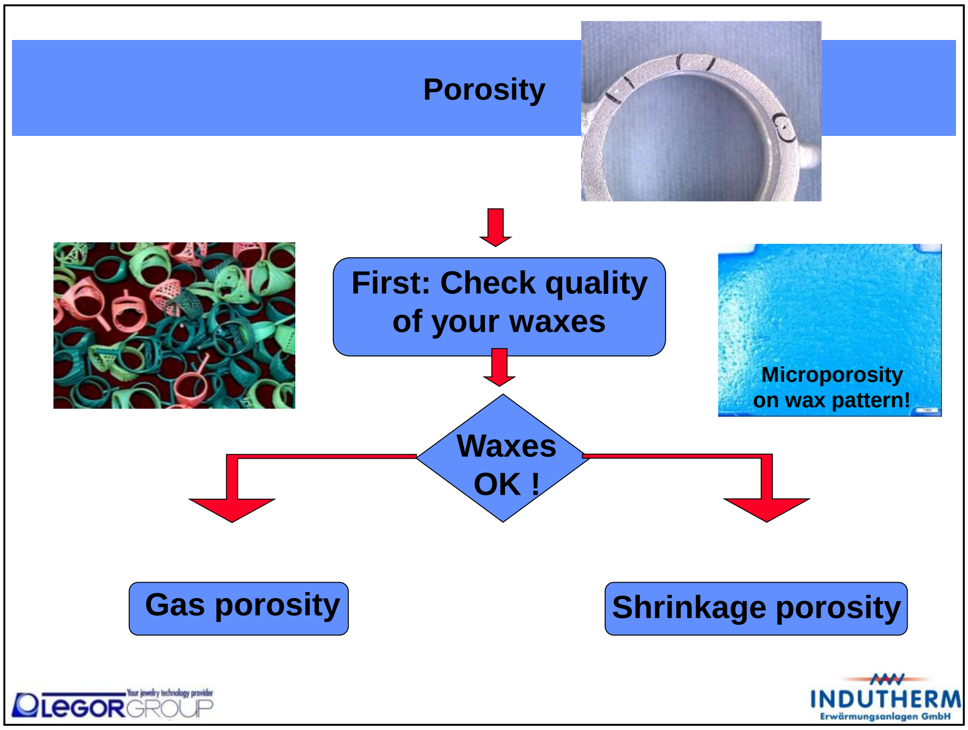
The minimisation of the occurence of defects, is only possible with improved knowledge and understanding about the possible sources of such defects.

It is of very high importance to understand that one of the main difficulties is to differentiate between a variety of defect types, which at first might look similar. Especially for different types of porosity also different measures to avoid them need to be considered, and the same is true also for other types of defects.

We will now summarise quickly a few main considerations using flow-diagrams, which hopefully will be helpful for your own future approach to analyse casting defects.



Porosity

First: Check quality of your waxes

Microporosity on wax pattern!

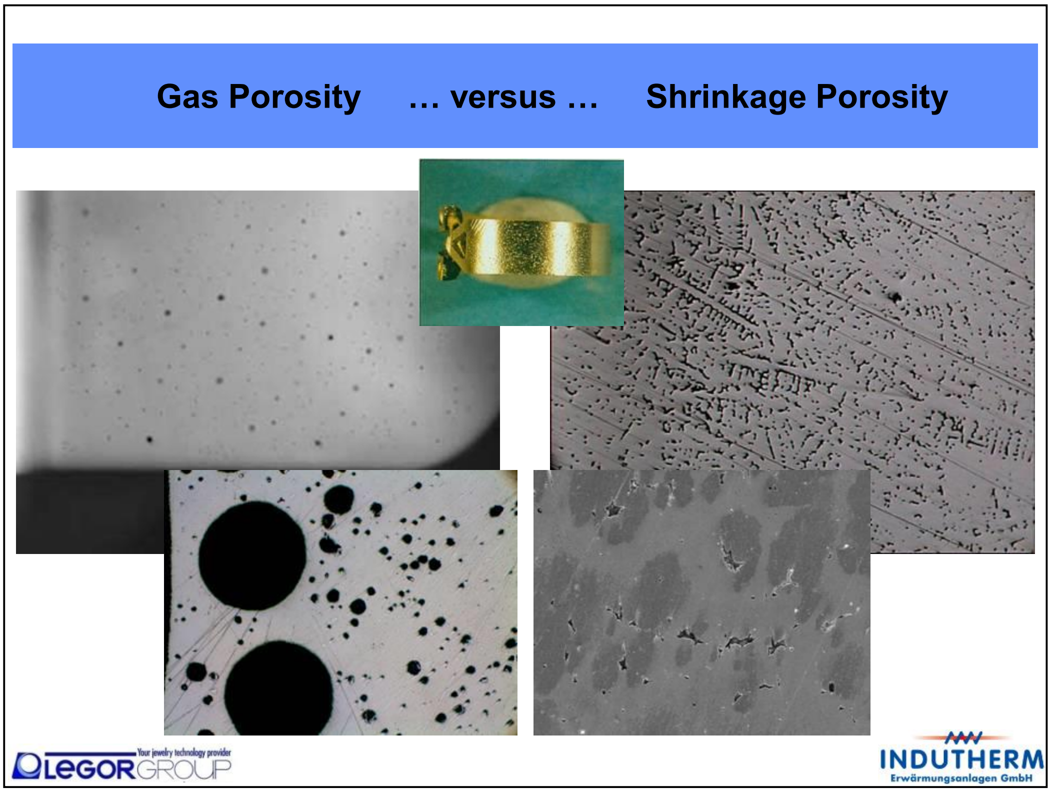
Waxes OK !

Gas porosity

Shrinkage porosity

In case of porosity, check the quality of your wax pattern first. Microporosity as well as big pores can already be present on the surface of your wax and will be reproduced on the surface of your casting. Excess humidity during storage and preperation of the waxes is a common cause for wax defects. Another possibility is that the rubber mould already carries some defects due to a low quality rubber or low quality prototypes used for preperation of the rubber.

If the wax quality is OK, try to categorise if the porosity looks more like shrinkage or gas porosity.

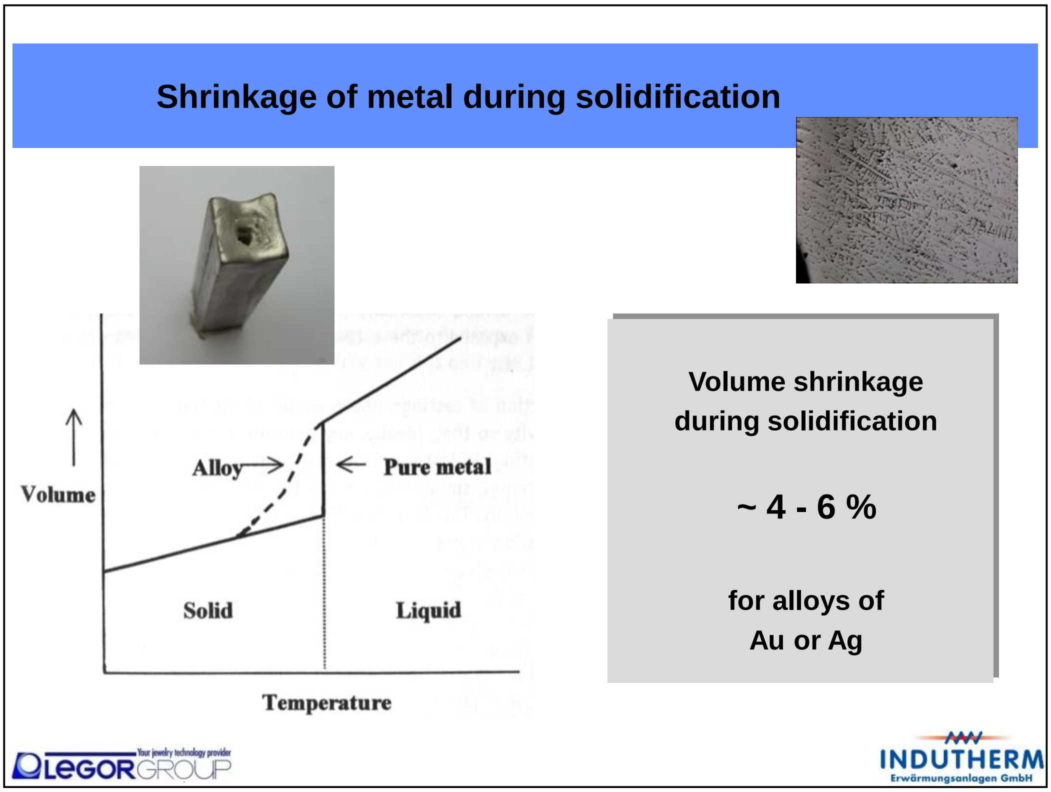


Gas Porosity … versus … Shrinkage Porosity

Shrinkage Porosity (right) shows itself as irregular shaped cavities, which in many cases follow a typical geometrical pattern.

Gas Porosity (left) shows itself as pin holes on the surface of the casting. As opposed to shrinkage porosity these holes are generally round and smooth in nature.

In practice, both types of porosity often overlap. Furthermore, in special situations gas porosity (caused by reaction with the investment material) can look very similar to skrinkage porosity. As a consequence, in many cases a destructive analysis in a lab is the only way to clearly identify the main cause for porosity. Identifying the real cause is essential to optimise process parameters so that the defect can be avoided.



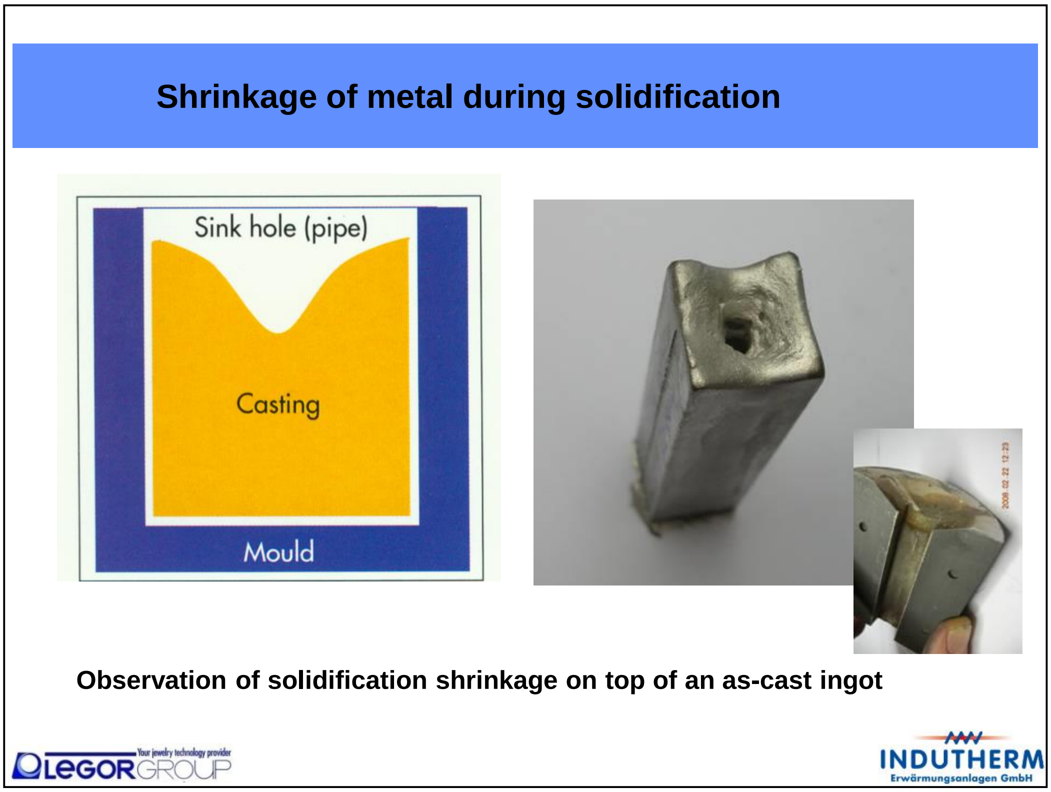
Shrinkage of metal during solidification

Volume shrinkage
during solidification

~ 4 - 6 %

for alloys of
Au or Ag

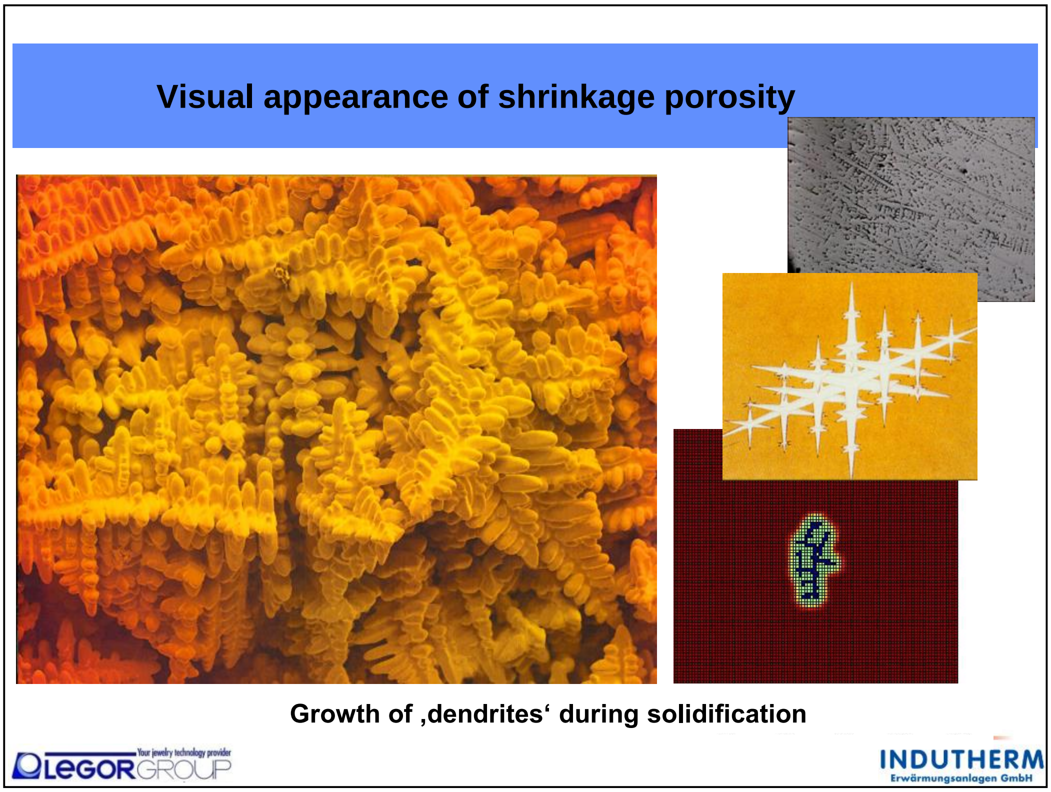
Shrinkage porosity is caused by the fact, that metals and alloys show a sudden reduction in volume when they solidifiy. For pure metals this happens at their particular melting points, whereas for alloys the volume shrinkage occurs over their particular melting range. The amount of volume shrinkage is in the order of 4-6 % for alloys of gold and silver.



Shrinkage of metal during solidification

Observation of solidification shrinkage on top of an as-cast ingot

The volume shrinkage of metals durings solidification can be directly observed in ingot casting. Solidification starts at the mould interface and progresses into the center. Due to the volume shrinkage a sink hole develops in the top central part of the ingot.



Visual appearance of shrinkage porosity

Growth of ‚dendrites‘ during solidification

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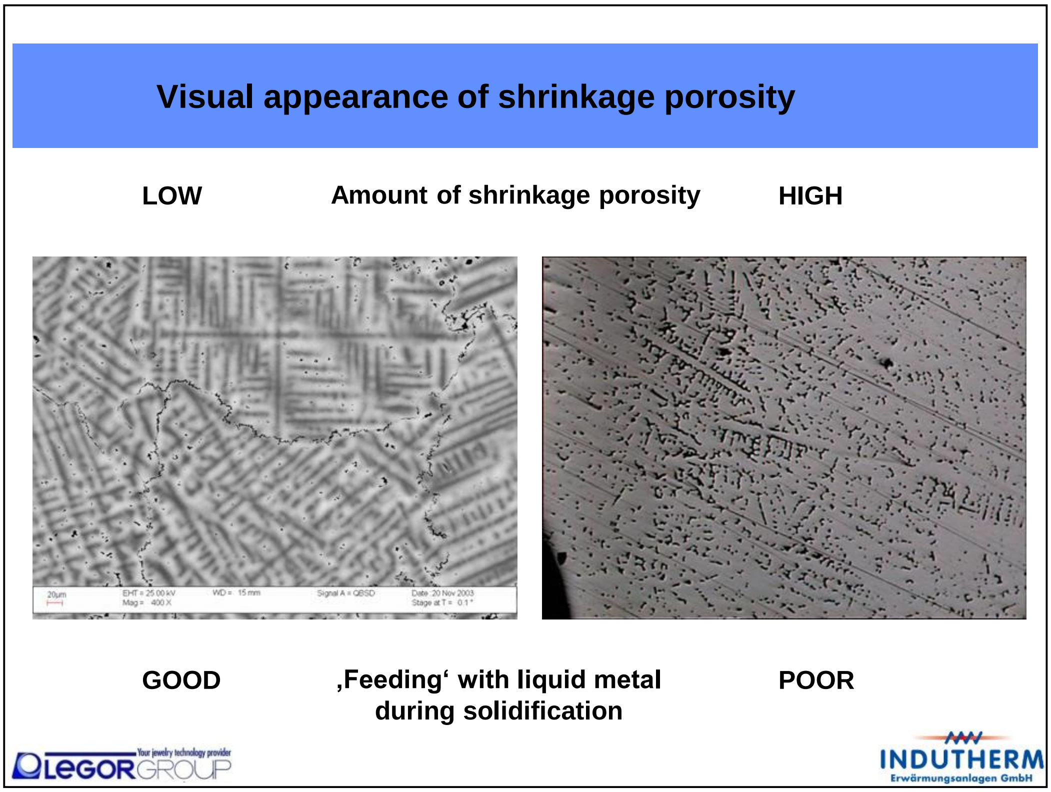
The typical geometrical pattern, that we observe on the surfaces of samples with shrinkage porosity (top right picture), is related with the shape of the metal crystals which grow during solidification. These crystals grow like branches of a tree and are called ‚dendrites‘. When they grow, liquid metal has to flow in between the branches of the dendrites to compensate for the shrinkage. This is called ‚feeding‘. If this is not working well, shrinkage porosity develops.

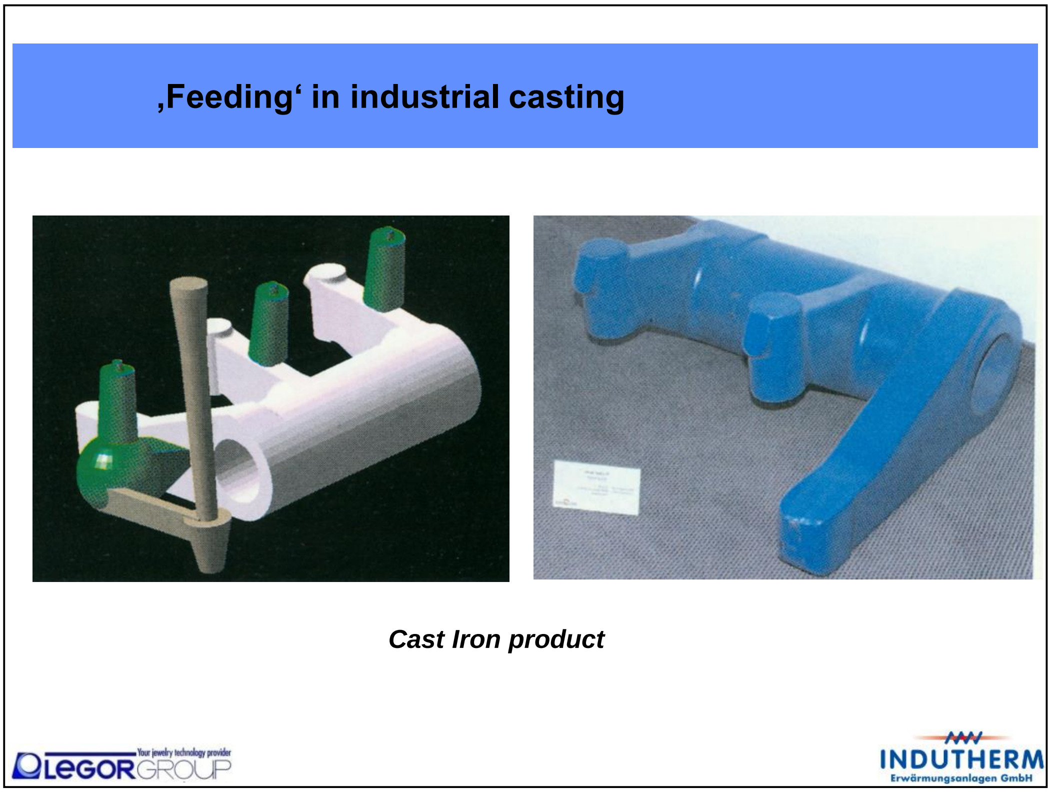


Visual appearance of shrinkage porosity

LOW **Amount of shrinkage porosity** **HIGH**

GOOD **‚Feeding‘ with liquid metal during solidification** **POOR**

If feeding with liquid metal during solidification works well, shrinkage porosity can be avoided. The different jewellery alloys have different tendencies to develop shrinkage porosity. White gold has higher tendency than yellow gold, and sterling silver has the lowest tendency. Avoidance of shrinkage porosity could be the focal topic of a seperate seminar. The next slides shall just remind you of the basic prinicple.



‚Feeding‘ in industrial casting

Cast Iron product

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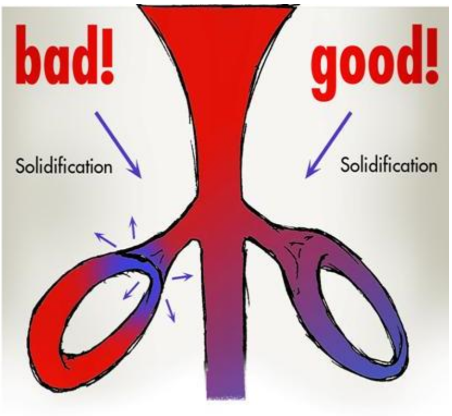
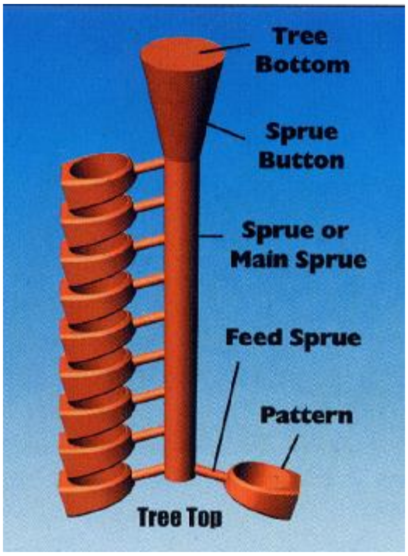
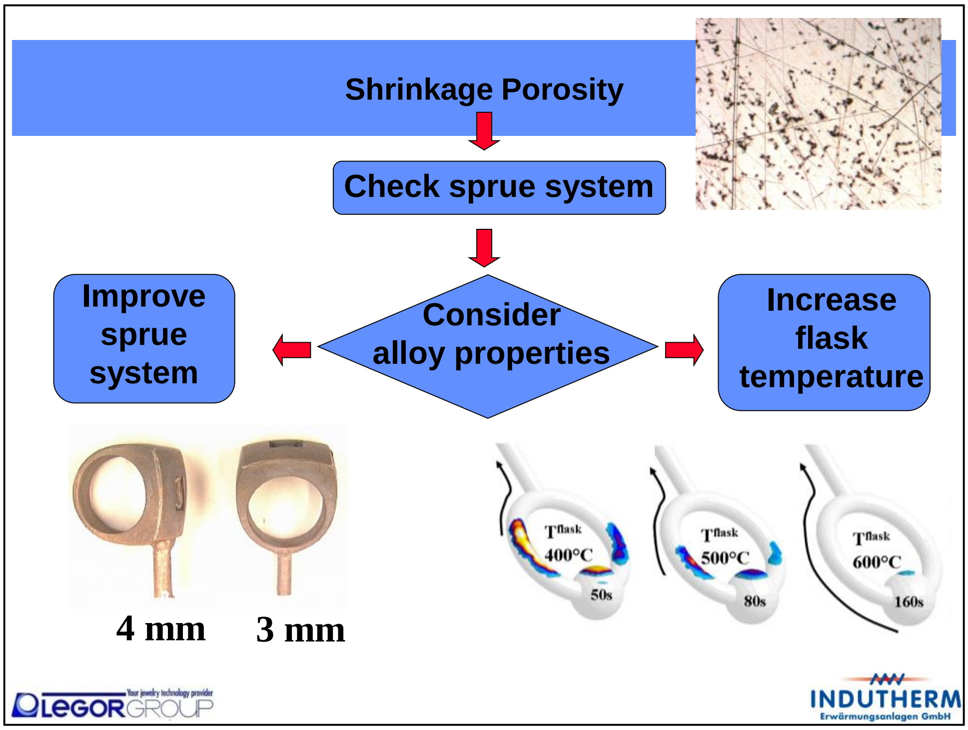
In industrial casting, for example of automotive components made of steel or aluminium alloys, big ‚feeders‘ are used. They continuously supply liquid metal to the solidifying part. Therewith the volume shrinkage in the final product is compensated. If optimum feeder dimensions and process parameters are used, the development of shrinkage cavities and porosity is finally restricted to the feeder itself, where it does not hurt.

‚Feeding‘ in jewellery casting





In jewellery casting, the main sprue together with the feed-sprues take over the role of the ‘feeders’. Hence, these parts of the tree are not only required for good form-filling during the pouring step. They also have to provide to the jewellery pattern a reservoir of liquid metal which compensates for the volume shrinkage during solidification. The optimum situation always is, that solidification starts at the outer part of the jewellery pattern and progresses continuously along the pattern, over the feed-sprue into the main sprue. Therefore it is always recommended to put the feed-sprue on the heaviest section of the jewellery item. The computer simulation video shows some examples for sterling silver casting.



Shrinkage Porosity

Check sprue system

Consider alloy properties

Improve sprue system

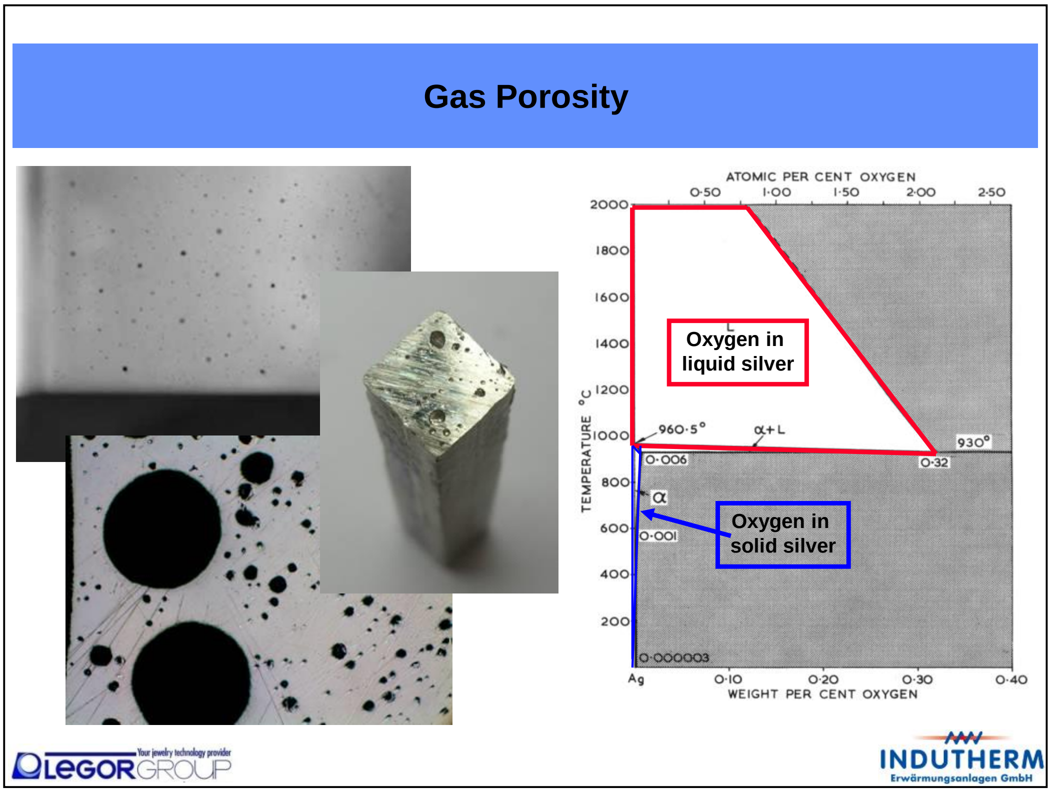
Increase flask temperature

Shrinkage pores almost always are very irregularly shaped and often appear very localised. In case that shrinkage porosity is most probably the trouble-maker, then the priority is to improve the sprue system.

The following options exist:

- Re-positioning the feed-sprue to the heaviest section of the pattern;
- Increasing the feed-sprue diameter;
- Reducing the feed-sprue length;
- Usage of multiple feed-sprues

If these measures do not work, it is also possible to carefully increase the flask temperature, but if porosity is getting worse, then there is most probably an investment reaction, leading to gas porosity.



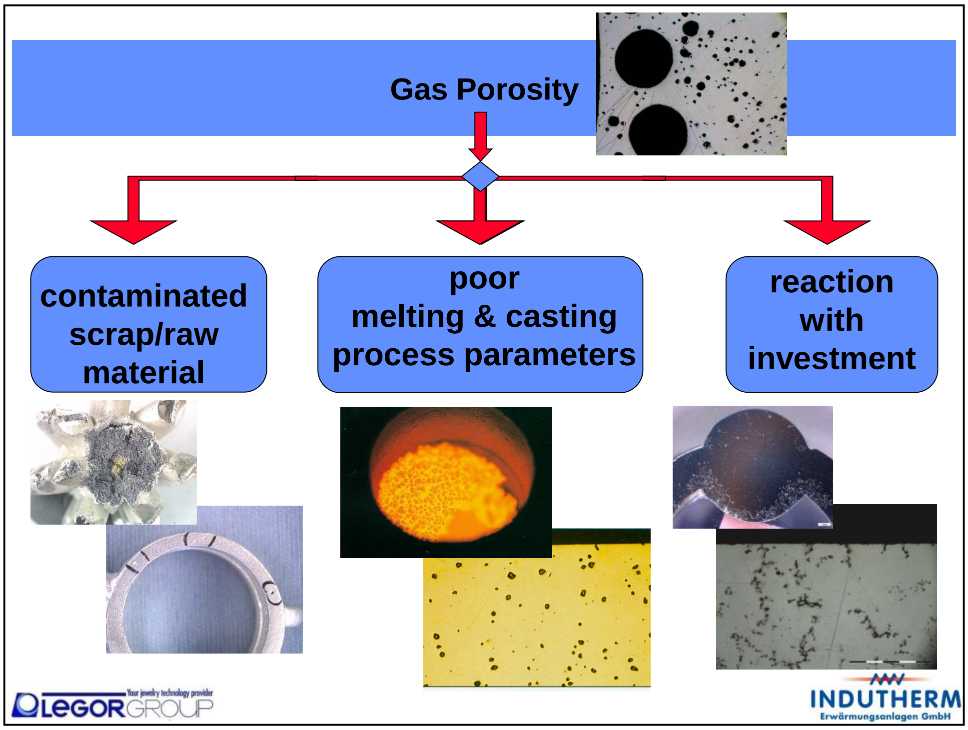
Gas Porosity

Oxygen in liquid silver

Oxygen in solid silver

As opposed to shrinkage porority, **gas porosity** shows itself as round-shaped holes on the surface of the casting. The sliced ingot shows a very severe case of gas porosity.

Gas porosity mainly is related to the property of melts to dissolve much larger amounts of gas than in the solidified state. (The diagram on the right illustrates this for the solubility of oxygen in silver.) Therefore, if the melt contains a too high gas content (for reasons which have to be discussed), gas tries to ‚escape‘ from the metal during solidification. In most cases gas bubbles then are finally entrapped in the solidified casting and become visible during surface finishing.



Gas Porosity

contaminated scrap/raw material

poor melting & casting process parameters

reaction with investment

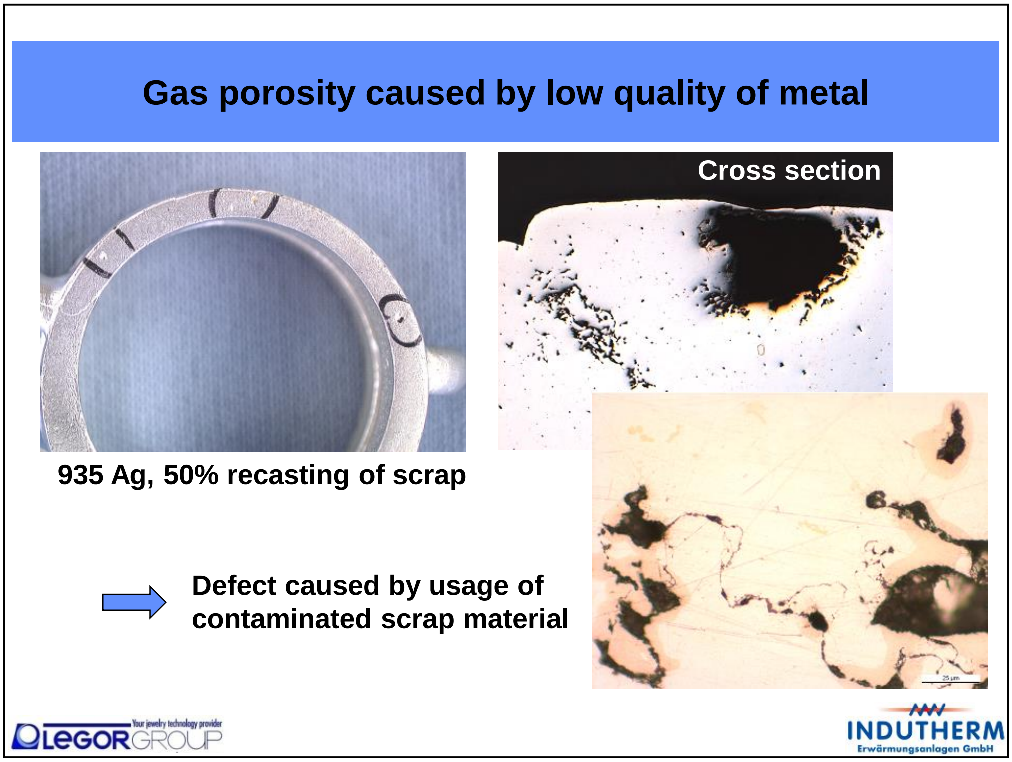
Gas porosity usually can be identified by spherical pores. In case of gas porosity, we have to consider in general three main causes:

-> Contaminated scrap material; usually leading to non-uniformly distributed pores, often comparably large sized.

-> poor melting and casting process parameters, usually leading to uniformly distributed pores (microporosity)

-> reaction with the investment; very frequent problem but often mixed up with shrinkage porosity, since pores are also localised and more irregular in shape.

From the case studies discussed today it will be clear that too high flask temperatures are a very frequent cause for gas porosity due to reaction with investment. Further or related reasons are: -> uneven burnout furnace temperature, -> too high casting temperature, -> poor dewaxing (rapid prototyping resins) -> poor quality investment (beyond shelf-life), -> poor storage conditions of investment, -> poor burnout process, -> degradation of graphite crucible.



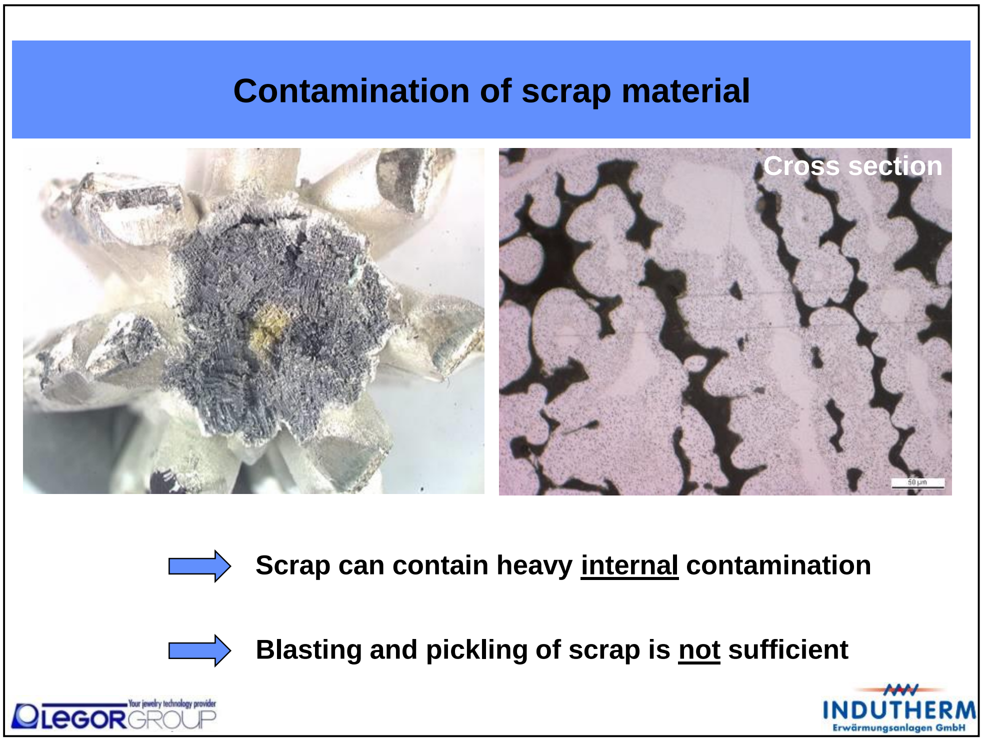
Gas porosity caused by low quality of metal

Cross section

935 Ag, 50% recasting of scrap

Defect caused by usage of contaminated scrap material

This example illiustrates severe gas porosity in a sterling silver casting: Large pores were visible on the as-cast ring shank surface. The metallographic cross section revealed high amounts of big and small gas pores, as well as inclusions of copper oxides and zink oxides. Such inclusions are a typical source for gas porosity. They can be caused by recasting of contaminated scrap material. Furthermore usage of good quality master alloy material and fine gold/silver is of large importance; low quality fresh metal is also a frequent cause for gas porosity, although less severe than in the case shown above.



Contamination of scrap material

Cross section

50 µm

- Scrap can contain heavy internal contamination
- Blasting and pickling of scrap is not sufficient

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Scrap can contain large amounts of heavy internal contamination. This can be caused by inclusion of slag or breakout of investment material. Another cause is internal formation of oxides, when hot flasks are cooled on air after casting. As a consequence, scrap must be cleaned very thoroughly before recasting. Blasting and pickling is required, but is not sufficient; proper ‚degassing‘ during remelting for granulation is essential.

The scraps recycling

1) Surface cleaning:
- blasting
- pickling
- tumbling

2) Regranulation
- remelting
- degassing

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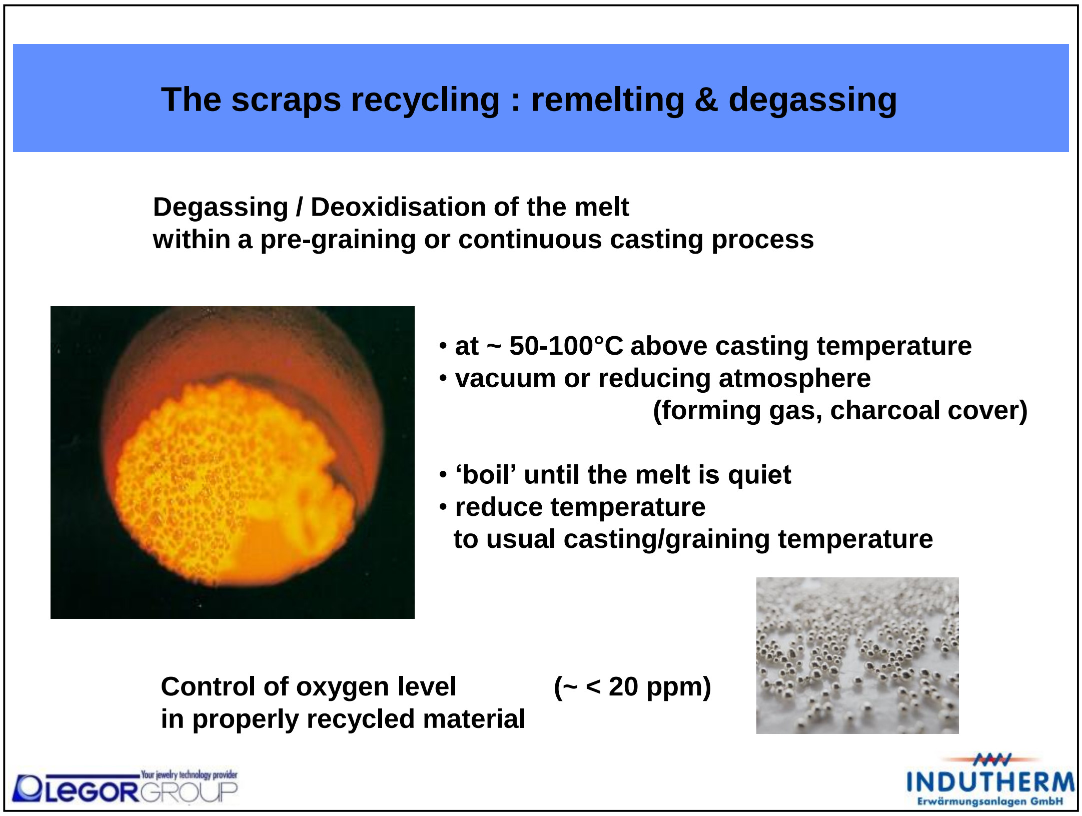
Particular attention has to be paid to the scraps recycling issue. A proper in-house recycling procedure is necessary in order to maintain high quality castings and involves:

-> Pickling to remove surface oxidation; -> tumbling to mechanically remove oxides and investment residues, .> remelting, degassing and granulating.

The top left picture shows how scraps should look after a proper cleaning cycle: perfectly clean and smooth. However, the top right picture also shows heavy internal contamination of scrap which can not be removed by pickling or tumbling. This is the reason for the final degassing + granulating step.



The scraps recycling : remelting & degassing

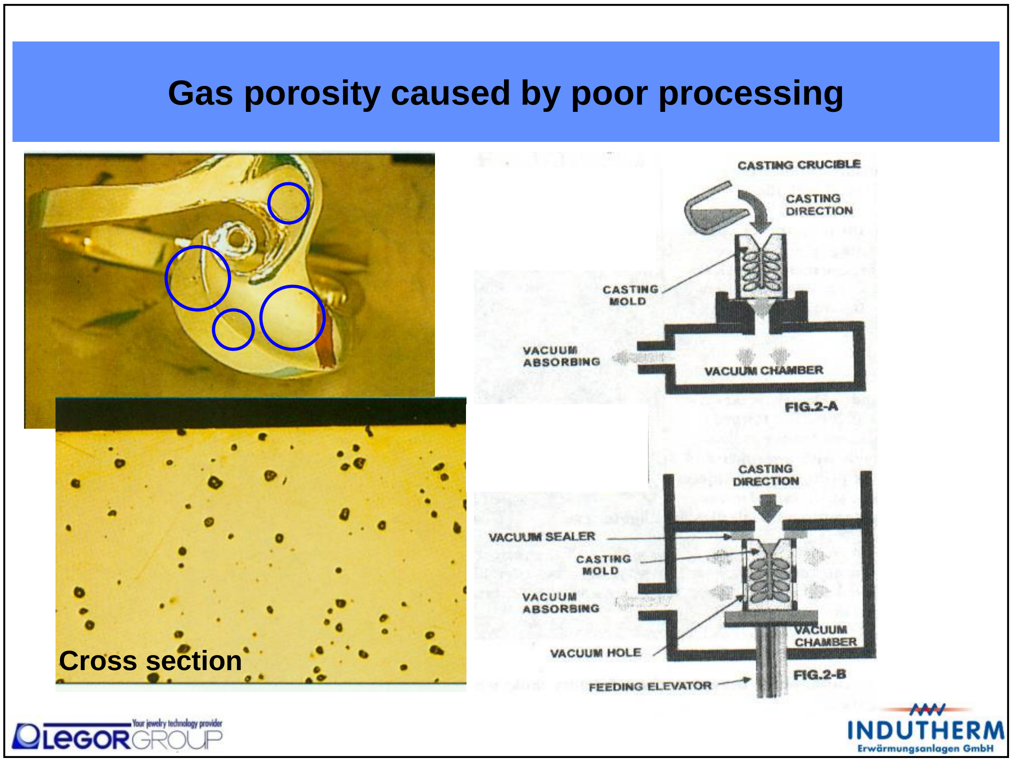
Degassing / Deoxidisation of the melt
within a pre-graining or continuous casting process

- **at ~ 50-100°C above casting temperature**
- **vacuum or reducing atmosphere**
  (forming gas, charcoal cover)

- **'boil' until the melt is quiet**
- **reduce temperature**
  to usual casting/graining temperature

Control of oxygen level (~ < 20 ppm)
in properly recycled material

Degassing of scrapps occurs similarly to what happen for degassing of fresch material. During this process the oxygen contained in the material is removed by a reaction with the graphite crucible. is an extremely active element that removes oxygen in the liquid metal and decomposes oxides. The result of this reaction can be seen through a bubbling reaction that shows us the removal of oxygen (as carbon monoxide and carbon dioxide). The higher the temperature of the melting bath, the stronger is the power from the carbon to remove oxygen. For silver, a good deoxydation temperature is from 1100 to 1200°C. For granulation of pure silver or alloys that doesn‘t contain volatile components (eg zinc), application of vacuum may also be useful. After degassing at high temperature, temperature is decreased at about 100-120°C over liquidus temperature and granulation starts.



Gas porosity caused by poor processing

Cross section

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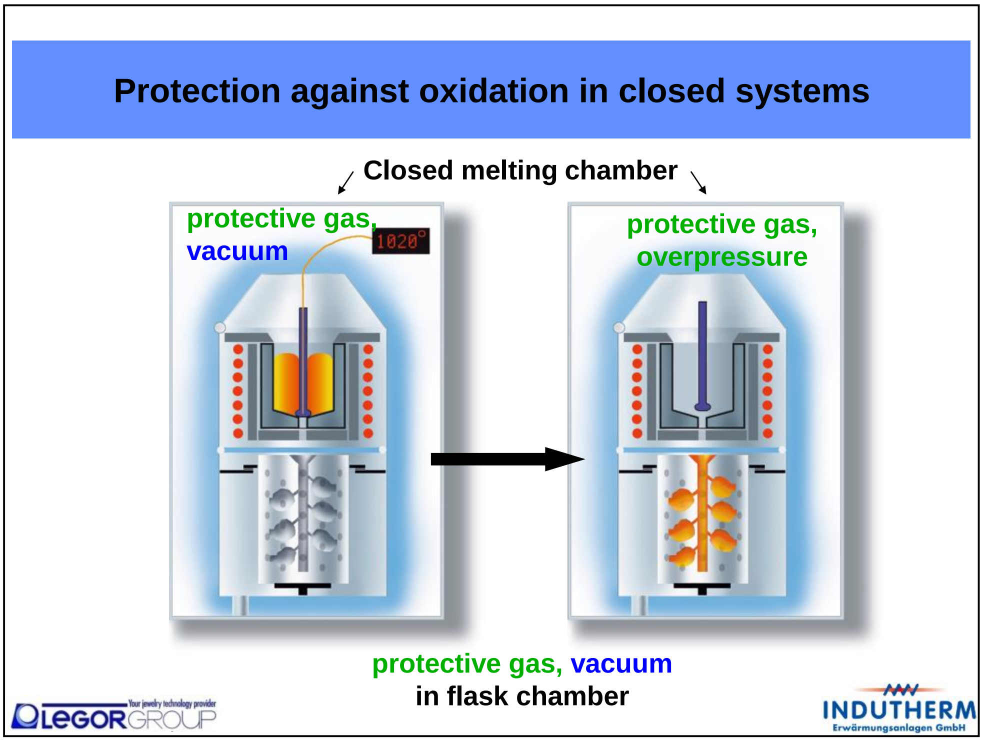
This is an example for gas porosity in an 18ct yellow gold casting. The metallographic cross section reveals spherical pores which are evenly distributed. In this case poor processing caused by usage of open melting systems and/or remelting of contaminated scrap was identified as the prinicipal cause for the defect. Melting in open systems provides a comparably poor protection against oxidation and uptake of oxygen by the melt (even if a protective gas cover is used) which is a frequent reason for gas porosity in jewellery castings.



Protection against oxidation in closed systems

Closed melting chamber

protective gas, vacuum

protective gas, overpressure

protective gas, vacuum in flask chamber

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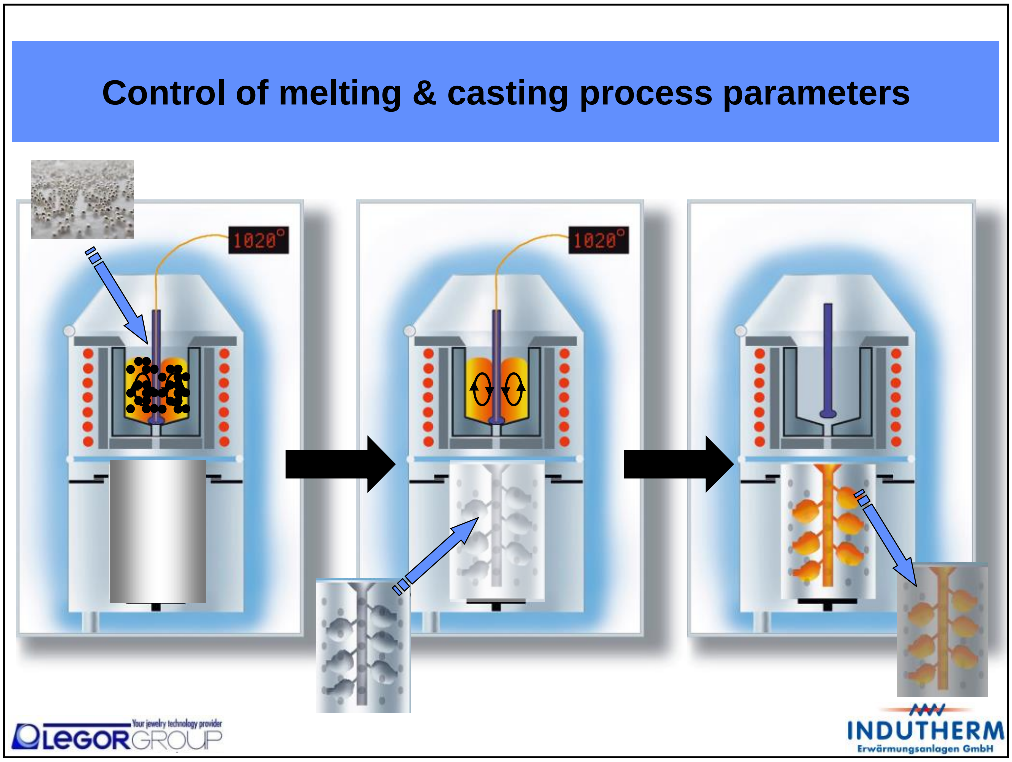
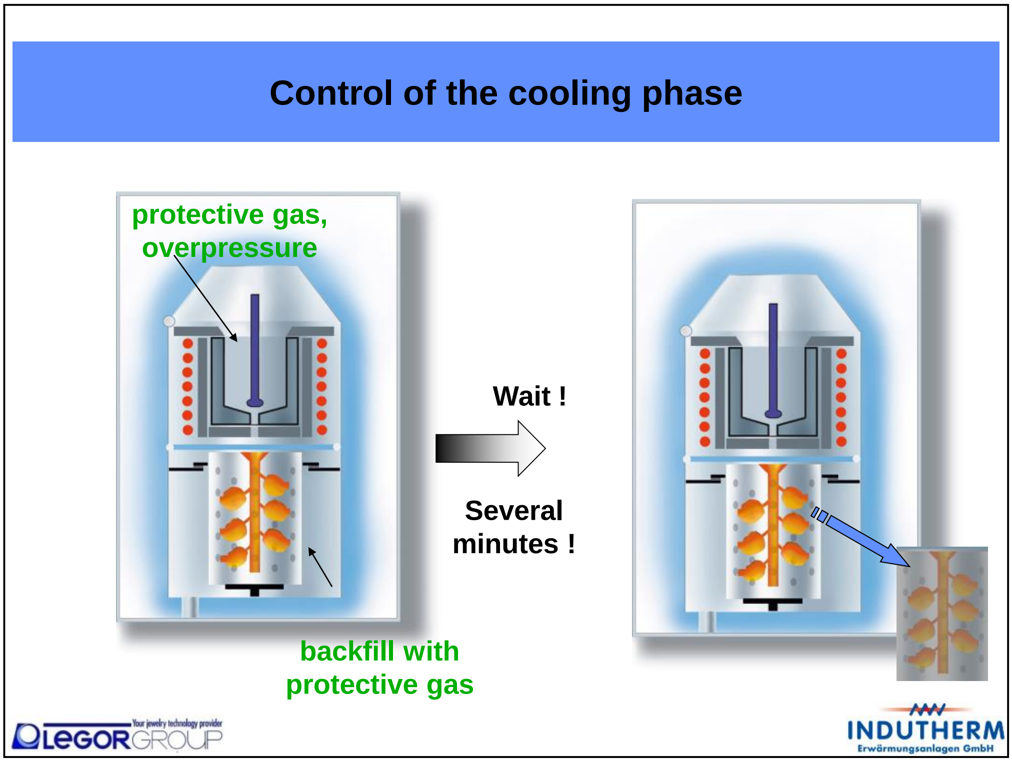
An important feature of modern casting equipment is that melting is carried out in a closed system. A protective gas cover can be more effective since the closed nature of the system does not allow entering of air from the environment. Even better conditions with protection against oxidation and uptake of gas (oxygen, hydrogen) from the atmosphere can be realised by either melting under vacuum or with a backfill of protective gas after evacuation.



Control of melting & casting process parameters

Also, remember that the melting and pouring phase consists of several consecutive process steps, which involve some in-between actions which should not be neglected if gas porosity occurs: In many manufacturing companies, the flask is loaded into the equipment after the metal is completely molten. However, it is recommended to wait after loading of the flask into the equipment minimum 1 min, better 2 min before start of pouring, so that the interior of the flask is effectively cleaned from air (by gas flow or vacuum) before pouring. The temperature loss of the flask during the melting time can be neglected. After pouring, remember always that the cooling phase of the flask needs to be controlled, too (see next slide).



Control of the cooling phase

protective gas, overpressure

Wait !

Several minutes !

backfill with protective gas

Especially for medium-to-heavy weight pattern the solidification time can be in the order of several minutes depending on flask temperature, weight of the pattern and alloy. There are many arguments for keeping the flask under protective gas or vacuum in the flask chamber for several minutes before removing and exposing them to air again. This is especially effective in combination with an immediate quenching step after removing the flasks from the flask chamber. These arguments include:

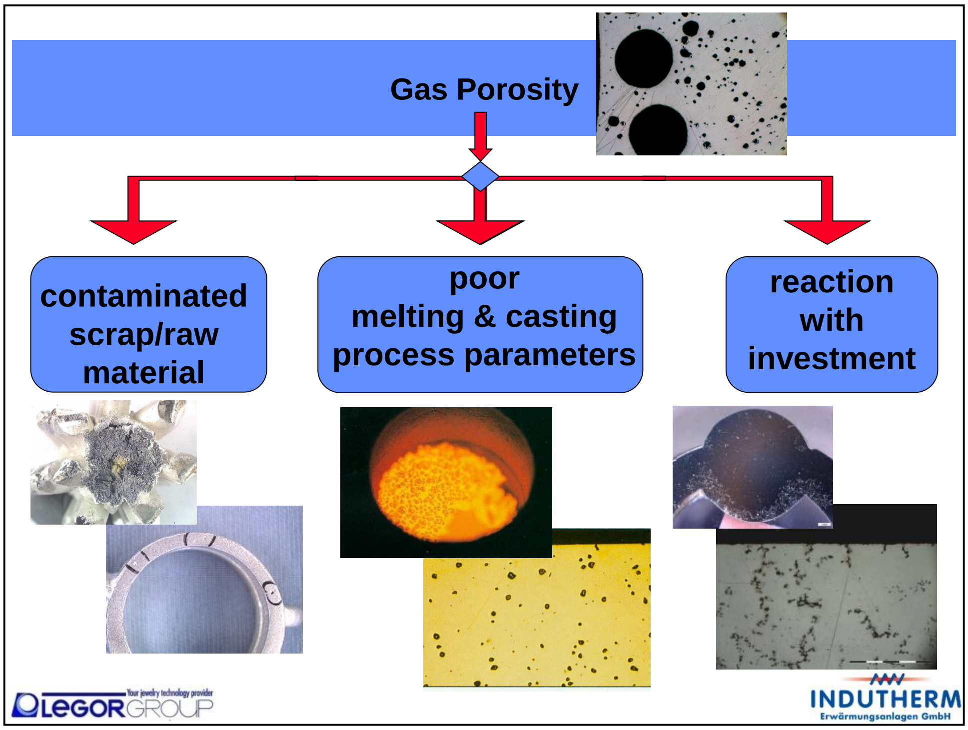
-reduction of gas porosity, since gas uptake by the still liquid metal is avoided,

-reduction of firestain (in sterling silver)

-improvement of scrap quality due to overall reduction of oxidation

-reduction of formation of hot cracks, since unnecessary stress on the metal in an too early stage is avoided.

Modern automated equipment offers the opportunity to restart the melting process for the next flask, while the former flask is still cooling under protective conditions inside the equipment.



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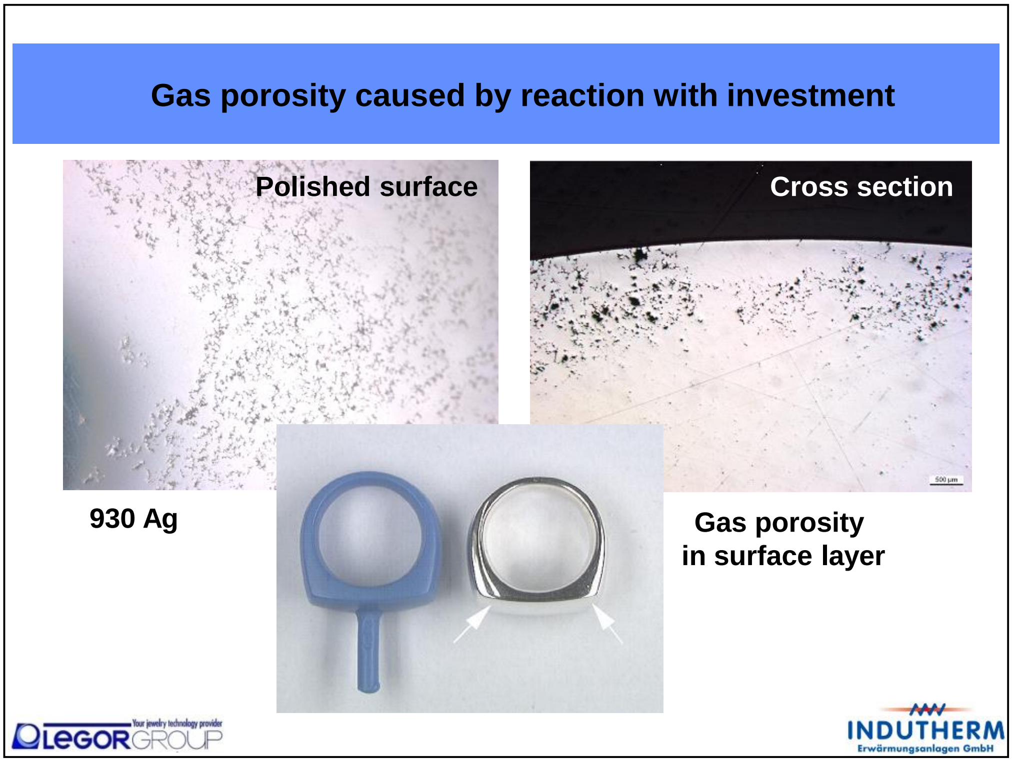
From many case studies it is clear that too high flask temperatures are a very frequent cause for gas porosity due to reaction with investment. Further or related reasons are: -> uneven burnout furnace temperature, -> too high casting temperature, -> poor dewaxing (rapid prototyping resins) -> poor quality investment (beyond shelf-life), -> poor storage conditions of investment, -> poor burnout process, -> degradation of graphite crucible.



Gas porosity caused by reaction with investment

Polished surface

Cross section

930 Ag

Gas porosity in surface layer

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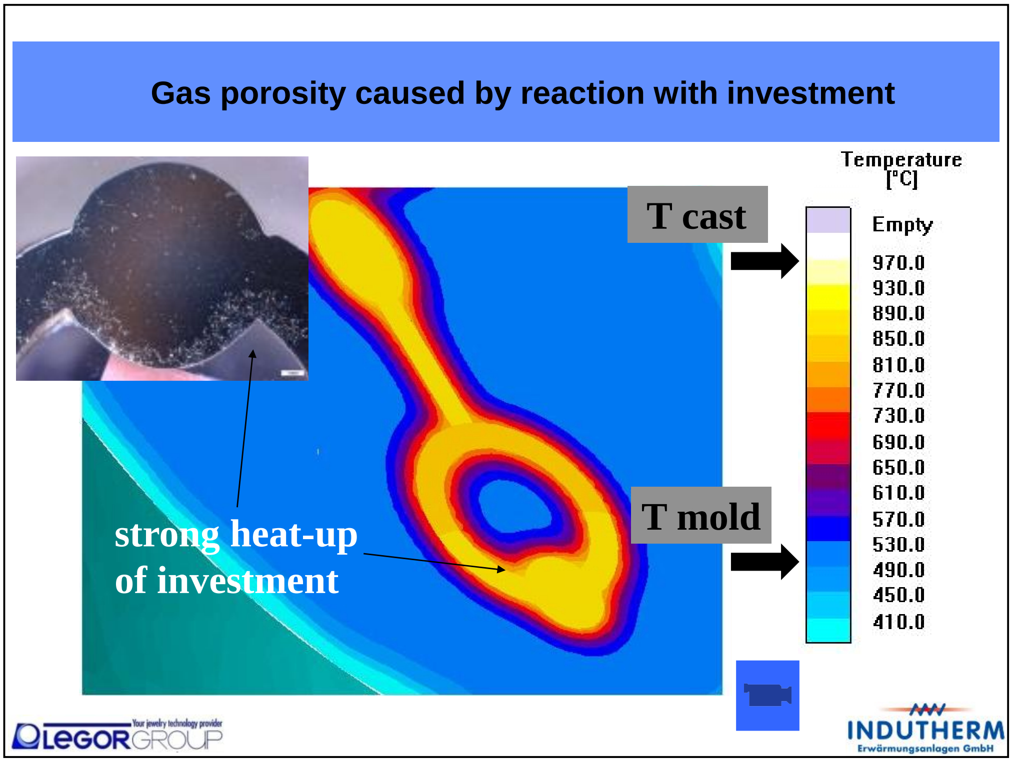
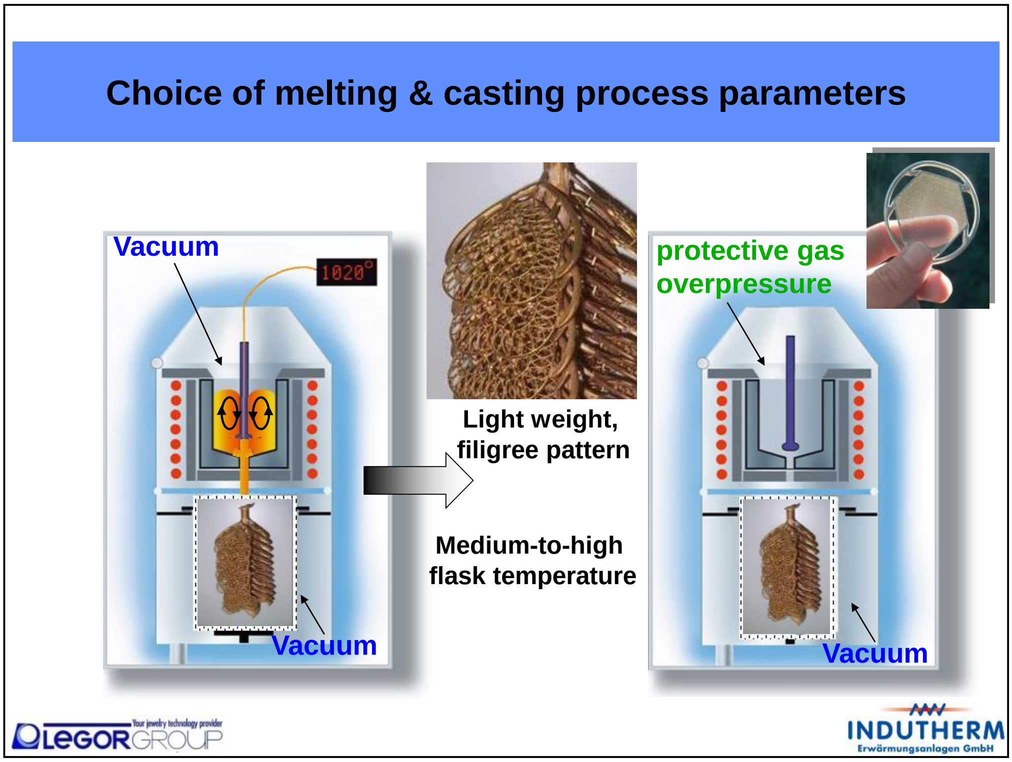
This is another example for gas porosity in a sterling silver casting. In this case the examination of the polished jewellery surface at first sight suggested shrinkage porosity. However the feed-sprue was well positioned at the heaviest section of the ring. Despite of that porosity occured. The metallographic cross section revealed also round-shaped gas pores; furthermore porosity was restricted to a surface-near layer. These features are characteristic for gas porosity caused by reaction with investment material.



Gas porosity caused by reaction with investment

Investment material is composed mainly of silica (silicon oxide) and gypsum (calcium sulfate). When the metal enters the mould, the boundary layer of investment material heats up quickly and strongly, as shown by the computer simulation video on this slide. When the flask temperature is too high, the heat-up is too strong and the investment material ‚decomposes': This means that gas is released from the investment material which in turn causes gas porosity. Decomposition of investment material is also triggered by poor dewaxing or burnout processes, as well as the usage of old batches of investment (beyond shelf-life). The danger for reaction with investment in general increases for alloys with high melting temperatures, for example Palladium-based white gold alloys, but is also an obvious problem for sterling silver alloys despite of comparably low melting temperature.



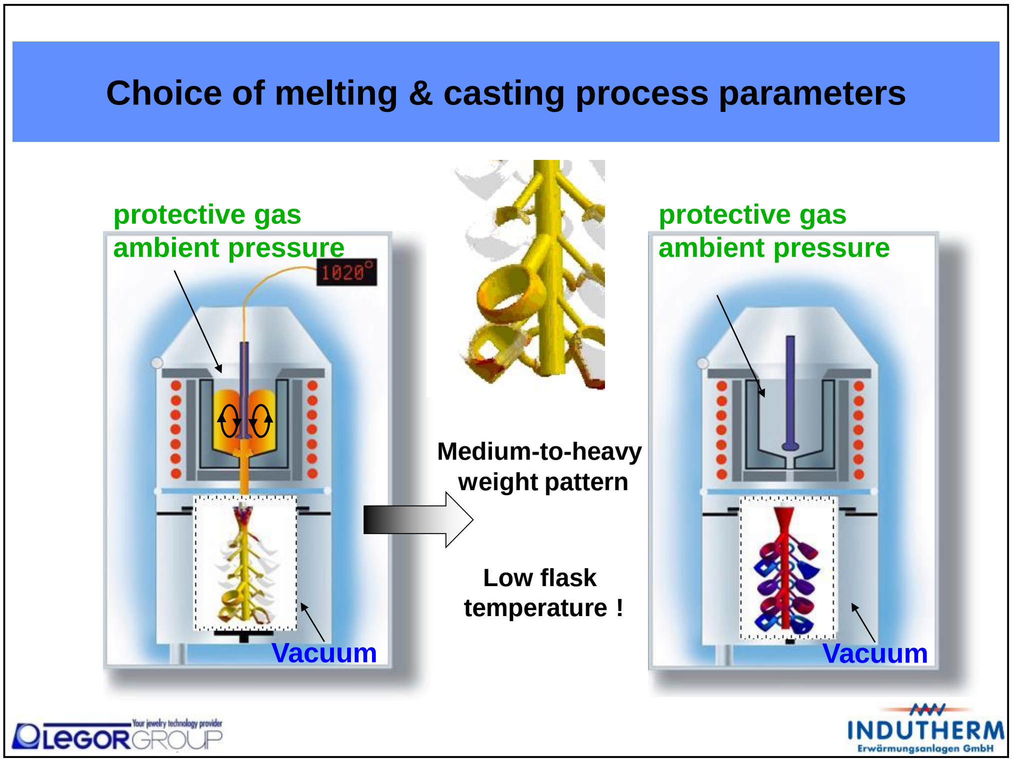
Choice of melting & casting process parameters

Light weight, filigree pattern

Medium-to-high flask temperature

For castings of **filigree, light-weight pattern** we usually recommend melting and pouring under vacuum in the melting chamber, and of course also vacuum in the flask chamber. Immediately after pouring and after the metal has left the crucible, an overpressure should be applied. The complete removal of residual gas from the flask chamber, together with overpressure assists to achieve complete formfilling even of the finest details.

The disadvantage of this pouring principle can be increased gas porosity due to reaction with investment, since the full vacuum in the flask interior increases the danger of decomposition of investment material as soon as it comes in contact with the hot melt. For filigree, light-weight pattern the risk is low, however,



Choice of melting & casting process parameters

protective gas
ambient pressure

Vacuum

Medium-to-heavy weight pattern

Low flask temperature !

protective gas
ambient pressure

Vacuum

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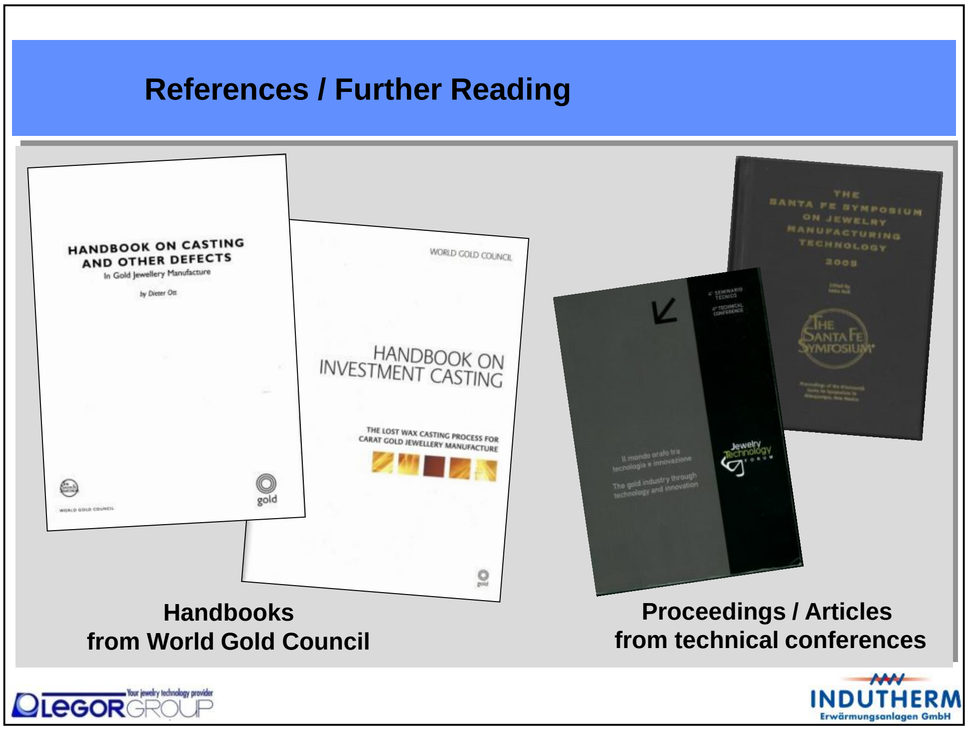
If you have to cast **medium-to-heavy weight pattern** we recommend melting and pouring with protective gas atmosphere (ambient pressure) in the melting chamber and with vacuum in the flask chamber. This contributes to minimising gas porosity if the flask temperature is chosen reasonably low. Application of vacuum also in the melting chamber during pouring would increase the danger for reaction with investment and gas porosity.

The disadvantage of this pouring principle can be less good formfilling, because the residual gas in the flask chamber is compressed by the incoming metal which exerts a backpressure. Furthermore the gas is heating up and expands, which reduces the filling speed of the metal flow even more. For medium-to-heavy weight pattern this should not lead to formfilling problems, however, and will even help to reduce turbulences during metal flow, erosion of investment material etc.



References / Further Reading

Handbooks
from World Gold Council

Proceedings / Articles
from technical conferences

Here is a list of further literature for those who wish to read more detailed information about the topics covered by the seminar:

1. "Handbook on Casting and Other Defects in Gold Jewelry Manufacture"; Dieter Ott; ed. Chris Corti, World Gold Council, London, UK; 1998 (reprint 2001);www.gold.org
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