New Material Design Leads to an Other Casting Quality – Solidification, Stress, Mechanical Properties

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Foundation of RWP

Pioneer
in Simulation
of Casting Process
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Facts of RWP

- 1984 RWP was founded after basic developments at the RWTH Aachen done by Dr. Konrad Weiß
- High experienced software company developing casting simulation software
- WinCast® and SIMTEC are our software products for simulation of casting and cast processes
- RWP has become a Global Company with branch offices in USA, China, Russia, Spain, Czech Republic, Korea, India etc.
- RWP is an expert in casting engineering and supplies you with technical seminars, engineering services and software developments
- RWP works as a partner of industry and universities for external development and research projects on national and international level

Main industrial fields of RWP are design and construction of optimized components, casting of metal and plastics, foundry process simulation and the simulation of welding, laser welding and process optimization
Increasing use of computer for component development

Possible application areas for software:

- CAD - construction
- Topology optimization
- Stability- and Structural analysis
- Life cycle calculation
- Production analysis
  - mould fill simulation
  - cast and solidification process
  - heat treatment and machining
- Crash analysis
- Vibration- und Acoustic analysis
- Flow analysis
- Multiple component system analysis
- Electromagnetism analysis
The tendency of callback in the automotive industry is growing.

**Different reasons:**

- more high tech with higher risk of failure
- shorten model cycles as well as shorten development times
- tight calculated development and production costs

**Possible way of solution:**

- virtual Product development
  - drastic reduction of development time
  - saving on Prototypes
  - efficient and faster introduction of serial production
  - **Saving of time, costs and material during the development process**

**Toyota**
Callback of 1.8 Million cars due to clamped gas pedals

„Sometimes it seems that the car driver will be misused as a test driver. “

A. DEMMEL (Leader automotive technique ADAC)

No. of callbacks during the last 10 years
[Source: ADACmotorwelt 12/2004]
Current Situation for Development of Castings by using CAE

The used physical properties are based on standard tensile tests => Homogenous Material

Design → CAE → Optimization → Tests → Release 01/02/...

Final product
- High safety factor
- High weight
- High costs
- Quality level not easy to increase

Conclusion
Due to the dependency of current material information no adequate forecast of the mechanical behaviour of the component
Current Situation for Development of Castings by using WinCast

Taking the material properties into account due to solidification time

Final product
- (Still) High safety factor
- Weight can be reduced
- High costs
- Quality level can be increased

Conclusion
Still dependency of standard material information so the forecast of mechanical properties still are not adequate enough
Virtual Component development - Possible results in the moment

Virtual component development of a cylinder head

Prototype introduction of series production

Life cycle prediction

FEM-Stability-calculation

Stress simulation
  - Casting process
  - Heat treatment
  - Machining

Determination of mechanical Properties

CAD-Construction
  - Topology optimization
  - Structural optimization

Mould fill- and solidification simulation

Basics

WinCast® The full line of Finite Element Simulation

R. Vomhof, 15.06.2010
The CAD data are the starting point

The macroscopic simulation is used for form filling and solidification

The result of the macroscopic temperature calculation can be used for the prediction of macroscopic mechanical properties

Residual and load stress can be superimposed in order to evaluate the limits for strength and fatigue

The prototype building is the target
Virtual Component development-
Possible results in the moment

CAD Data

CAD Data is generally already available during the various component development steps. Initial simulation results for the casting process chain can be achieved even with a low degree of detail of the component.

CAD Data is available as solid models and can be used for simulation after transformation into the STL-Format.
Form filling and solidification

Calculations can only be done in the area of $10^{-2} - 10^{-3}$ m.

Calculation of form filling and solidification is achieved using differential equations (Navier-Stokes, Fourier).

Physical data is necessary for the simulation.

Micro-models are necessary in order to determine solidification phenomena.
The macroscopical statements were developed using empirical investigations. The results are very close to those of investigations on real.

The various models are in development and need more effort in research and development.
Residual- and Load stresses

Various physical/mechanical characteristic data are required for consideration of the local mechanical characteristics within the.

The residual stresses are the result of the cooling sequence during casting and solidification.

The load stresses result of the calculation of the various load situations.

The calculation of these various data can be achieved via virtual material development.
Life cycle definition

Life cycle definition is achieved by comparing the various load collectives with the local stress cycle diagram.

The calculation of the local stress cycle diagrams is developed from the macroscopic temperature profile.

Solidification conditions and composition must be considered when calculating the local stress cycle diagrams.
Prototype / Series production

The effort put into producing components after the casting process chain are not only usable for the development of prototypes. Simulation of the production chain, and therefore the influence on the appropriate component quality areas, deliver results which are used for the design of components, tools and processes.

Prototyping will continue to be necessary in the future, however, the number of components will be greatly reduced due to the capabilities of virtual component testing.
The consequence of different wall thicknesses and local conditions leads to different temperature gradients and solidifications times.

Micro structure is not homogenous.
Distribution of Mechanical properties are within a range.

What must be done?

The demand to get more and more information about the material properties already in the design stage of a new component leads to the necessity to know more about the building mechanism of the basic matrix. Here we give one important step to get more detailed information on the mechanism of building different mechanical properties.
Improvement of the forecast of mechanical characteristics

The classical approach for the evaluation of data is time-consuming and strongly dependent on test conditions. New alternatives have to be found in order to be able to describe the various structures and the local conditions within the components.

**Lets take a different route**

- We create various virtual basic structures and test their characteristics.
- The characteristics are validated with targeted experiments.
- Construction of synthetic structures
- Comparison of real and synthetic structures
- Creation of a correlation between solidification conditions and synthetic structures.
- Creation of a database for the calculation of the expected mechanical properties.
Development of tools

Tool 1
The coupling of micro- and macro-simulation with the consequences on the solidification sequences combines nucleation and growth as well as the release of latent heat with the expected structures.

Tool 2
Micro-FE shows the possibilities and limits of the various materials and processes. This method can also be used to create missing physical and mechanical data.
With the crystal, eutectic, matrix calculation we can see what happens during solidification. The resulting mechanical properties can not be defined. Therefore we will have a look at the micro FE analysis to get more information about the relationship between microstructure and mechanical properties.
The tests of the mechanical properties are done with a micro tensile test.
Mono Materials

Mg, A99, Si, Fe Database

[N/mm²]

0,00 50,00 100,00 150,00 200,00 250,00

Mg A99 Si Fe

tests
We are interested in the mechanical properties in specific areas of a real microstructure. We need to know how the influence of the silica in the Alpha phase will be (A), also we would like the influence of the porosities (B).
We build the finite Element mesh to have a description of the matrix. The red areas represent the pores.

With this method it is possible to see the influence of the shape of porosities.
Here we just bring in the silica distribution into the Alpha matrix. Different shapes and sizes can be built.
The view through the testing part shows the distribution of the different „disturbants“. This is possible in all directions.

Model building
Rebuilding of Real Micro Structure

Tensile Test synthetic

Alloy synt 6 with real distribution A99 Si 6 %

Alloy synt 7 with real distribution A99 Si 6 % and porosities

Alloy synt 8 with real distribution A99 Si 7 %

Tensile test alloy synt no 6 -8 to compare real distribution of alloying elements
Influence of real distribution of Si and porosities

Comp A99 vs A99 Si real Distribution

- Alloy synt 8 (magenta)
- Alloy synt 6 (yellow)
- A99 Data Base

- A99
- A99 3D Si 7%
- A99 S6 %
Mould filling animation
Example Stub Axle

Temperature field animation
Example Stub Axle

Defect building animation
Solidification time
Example Stub Axle

Hardness distribution
Example Stub Axle

Tensile strength distribution
Principle stress distribution with respect to classical mech. properties
Principle stress distribution with respect to synthetical mech. properties
Conclusion

Virtual component development with Micro FE

Prototype introduction of Series production

Life cycle prediction

Prototype introduction of Series production

FEM-Stability calculation

Stress simulation

Matrix determination Micro FE

Defect calculation and graphit expansion

Mould fill- and solidification simulation

CAD-Construction

Conclusion

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Further work to do

Determination of real matrix distribution

Determination of real mech. properties

Determination of matrix solidification time relationship

Creation of a building set for different alloys

Etc.
Thank You