Application Limits of Low-Ductile Cast Iron for Radioactive Waste Containers

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**Background**

**Current situation**

- Large amounts of contaminated metal waste arise when decommissioning and dismantling nuclear installations.
- If it were possible to reutilize part of it as normal non-radioactive material, the volume needed in final storage facilities and, as a result, also costs could be reduced.

**Idea**

- Use the scrap metal directly during the production of cast iron containers for final disposal of radioactive waste.
- The necessary technology already exists. It is possible to create various new grades of nodular cast iron apparently suitable as container material → Poster #36.

**Consequences**

- Scrap metal recycling during production of nodular cast iron has effects on safety-relevant properties of the material.
- The material’s ability to deform plastically and its resistance to crack initiation and propagation are less compared with the ductile iron normally used for cask manufacture.
- A large degree of scrap high-grade steel has a very adverse effect.
- The effort to qualify this new material for safety-relevant applications is increasing.
EBER research project

• In the EBER research project “Development of assessment methods for transport and storage containers made of ductile iron with increased contents of metallic recycling material” BAM is examining which safety margins for such low-ductile iron exist.

• New low-ductile iron grades are called GJS/R.

Are the safety margins sufficient to manufacture containers according to IAEA regulations, German repository acceptance criteria and interim storage requirements?

• Numerous drop tests with original size cylindrical casks and cubic containers as well as components of different ductile iron grades have been carried out.

• Previous experimental and numerical research on components made of cast iron with increased contents of metallic recycling material put the main emphasis on a stress analysis of components without any material defects → Proc. PATRAM 2004

• GJS/R fracture behaviour is examined now by drop tests with container-like components artificially pre-cracked with notches.
**Component tests**

- Only a few drop tests can be carried out with prototype casks due to the effort involved and cost reasons.
- Fundamental correlations are examined better in a series of component tests with container-like models under exactly defined and well reproducible boundary conditions.
- Suitable models must demonstrate behaviour representative of the examined cask type.

- Hollow sections with a volume of 1100 mm x 1100 mm x 820 mm and wall thickness of 160 mm are suitable for cubic containers.
- Such models can be manufactured simply and comparatively cheaply in larger quantities.
- They show the bending vibrations typical of cubic structures.
- The wall thickness corresponds with that of the original container particularly because of comparable cooling conditions of the casting.
Experimental set-up

• Experimental set-up is based on the acceptance criteria for the German KONRAD repository.
• The test object should drop onto a foundation representative of the final repository, which has to be modelled by a concrete foundation.
• Two series of components were investigated with slightly different geometrical properties: series B with a flat bottom, and series C with a 10 mm thick bottom ledge under the side walls.
• This bottom ledge represents, for example, a construction optimization to reduce the load on the body.
• In this way, stress types and values are different in the two types of hollow sections.
• The test temperature was lowered conservatively to -40°C.
Machined notches

- Notches were machined into 8 of the hollow sections available.
- These notches simulate conservatively postulated material defects by an artificial crack-like flaw so that fracture mechanics methods can be used for the safety assessment of the component.
- Long notches of constant depth are defined as the geometrical shape.
- The notches were machined at different places because they had to be positioned near high stresses in the structure.
- Series B had notches in the middle of the walls (two outside on the side walls, one inside on the bottom side).
- Series C had notches inside on the both bottom fillets and, additionally, in the middle of the top side.
- All the notches were 16 mm deep (1/10 of wall thickness).
- The advantage of large flaws is that a small drop height can be chosen to adjust the needed critical stress intensity to the flaw position.
- An involved mechanical procedure was used to get a notch tip radius of 0.1 mm at an opening angle of 60°.
Finite element model

- The experimental set-up was described as full model incl. real target.
- Test conditions have to be reproduced as realistically as possible.
- Complete layered foundation was modelled on top of the IAEA test stand target. Infinite elements formed the boundary of the ground beneath. Further boundary conditions were not necessary.
- Drop height was taken into account by the initial velocity.
- The elastic-viscoplastic material model for cast iron used measured rate-dependent flow curves.
- The concrete slab and a mortar layer connecting with the IAEA target were described by an elastic-plastic material model with hardening.
Numerical stress analysis

- Fully dynamic numerical calculations were executed to examine the stresses.
- The critical drop height was estimated to 0.7 m on the correlation between stress, critical crack depth, crack shape, and fracture toughness.
- A critical height of 0.8 m was fixed because of the unavoidable small impact angle in practice as opposed to an ideal flat impact.

Measured and calculated strains inside in the middle of the bottom of the hollow section C1 (drop height: 0.8 m, impact angle: 1°)
Crack initiation depending on the notch load

Drop test C1 (0.8 m, -40°C)  
critical drop height 
• **no damage** of the concrete slab 
• microcracks at one of the notches in fillet

Drop test C3 (1.8 m, -40°C)  
about 50% overload  
**no damage of concrete slab**  
**total failure at the notch in one of the fillets**

Drop test C2 (3.2 m, -40°C)  
double the critical load 
• **damage** of the concrete slab 
• central cracks starting from notches in fillets did stop
Construction optimization

with construction optimization
(bottom ledge under the side walls)

without construction optimization
(flat bottom without bottom ledge)

Drop test C2 (3.2 m, -40°C)
• damage of the concrete slab
• cracks at notches

Drop test B2 (3.2 m, -40°C)
• no damage of the concrete slab
• total failure
Drop test with original size prototype cask

- Prototype cask testing was carried out in accordance with the KONRAD repository acceptance criteria.

- The scenario is a bottom drop test from a height of 5.55 m (5 m plus extra height for missing contents) flat onto the reference target at a temperature of -20°C.

- Four notches (89 mm long, 6.6 mm deep) were machined in the fillets and one notch (122 mm long, **16 mm deep**) in the middle of the inside bottom.
Drop test with original size prototype cask

• Long cracks appeared in the test.
• The overcritical notch in the container bottom caused failure by fracture.
• The size of this artificial flaw was designed according to current size limits in non-destructive testing for cast iron grades with a fracture toughness twice that of the material here.
• An improved test procedure was the test object hitting the target almost ideally in the flat position.
Conclusions

- The cast iron presented is a low-ductile material with increased contents of metallic recycling material. It has nothing to do with the CASTOR® material !!!!!!

- Experimental results show clearly that overcritical flaw sizes cannot be tolerated.

- Large flaws investigated do not appear in the real material. One may not conclude on possible drop heights of real casks directly from the low critical drop heights of the examined components.

- The material properties of low-ductile cast iron, cask designs, stresses in cask structures and safety aspects show that the fracture toughness of the material and stress intensity factor of flaws must be harmonized very closely.

- In respect to material, fracture toughness should be increased if possible.

- In respect to safety assessment, further drop tests with original size prototype casks will be carried out in 2007 and 2008 with improved low-ductile cast iron grades.

- The story goes on …

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