



**Working Report 2005-53**

# **Test Manufacture of the Canister Insert I35**

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## **TEST MANUFACTURE OF THE CANISTER INSERT I35**

### **Abstract**

This report describes the insert-manufacturing test of a disposal canister for spent nuclear fuel that was made by Metso Foundries Jyväskylä Oy, in June 2004 on contract for Posiva Oy.

The test manufacture was a part of the co-operation development programme of encapsulation technology between SKB AB and Posiva Oy.

Insert casting was specified according to the current manufacturing specifications of SKB. The canister insert was of BWR-type with integral bottom. This was the second trial manufacture of this type of insert in Finland and, in total, the third test manufacture of insert by Metso Foundries Jyväskylä Oy.

The result fulfilled all the requirements but the material mechanical properties of the cast material. The measured ultimate strength and elongation at rupture were lower than specified in the upper part of the cast. The reason for this was revealed in the metallurgical investigation of the cast material. The cast contained slag (dross). Avoiding the dross formation will be the most demanding challenge of the forthcoming development of the cast procedure.

**Keywords:** canister insert, nodular cast iron, disposal canister for spent nuclear fuel

## LOPPUSIJOITUSKAPSELIN SISÄOSAN KOEVALMISTUS NUMERO I35

### Tiivistelmä

Tässä raportissa kuvataan käytetyn ydinpolttoaineen loppusijoituskapselin sisäosan valmistuskoe, joka suoritettiin Metso Foundries Jyväskylä Oy:n valimossa kesäkuussa 2004 Posiva Oy:n toimeksiannosta.

Koevalmistus oli osa SKB AB:n ja Posiva Oy:n välistä kapselointiteknologiaa koskevaa yhteistyössä tehtävää teknologian kehitysohjelmaa.

Sisäosan valun laatutavoitteet oli määritelty SKB:n senhetkisten valmistusspesifikaatioiden mukaisesti. Kanisterin sisäosa oli BWR-polttaineelle tarkoitettua tyyppiä ja siinä oli kiinteä pohjapäätty. Valmistuskoe oli tällä sisäosatyyppillä toinen Suomessa suoritettu ja kaiken kaikkiaan Metson Jyväskylän valimon suorittamana valukokeena kolmas.

Valmistuskokeen tulokset täyttivät vaatimukset kaikilta muilta osin paitsi valumateriaalin mekaanisten ominaisuuksien osalta. Valukappaleen yläpäästä mitatut murtolujuuden ja murtovenymän arvot jäivät vaatimusten alapuolelle. Syy tähän paljastui valumateriaalin metallografisessa tutkimuksessa. Valumateriaali sisälsi kuonaa (drossia), joka alentaa sitkeyttä. Kuonan syntymisen estäminen tulee olemaan valmistusmenetelmän jatkokehityksen keskeisin tavoite.

**Avainsanat:** kanisterin sisäosa, pallografiittirauta, käytetyn ydinpolttoaineen loppusijoituskanisteri.

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## 1 INTRODUCTION

This report describes the insert manufacturing test of a disposal canister for spent nuclear fuel that was made by Metso Foundries Jyväskylä Oy, in June 2004 on contract for Posiva Oy.

The test manufacture was a part of the co-operation development programme of encapsulation technology between SKB AB and Posiva Oy. The SKB identification for this insert is I35.

Insert casting was specified according to the manufacturing specifications of that time (SKB Drawing 00004-122, rev D, Procedure KT0704, rev 4, Technical specifications KTS011, rev 3, KTS021, rev 3 and KTS022 rev 1). The canister insert was of BWR-type with integral bottom. This was the second trial manufacture of this type of insert in Finland and, in total, the third test manufacture of insert by Metso Foundries Jyväskylä Oy.

## 2 INSERT SPECIFICATION

The insert test manufacture was ordered according to following specifications.

The steel profile cassette used as the central core of the cast is given in drawing SKB 00004-121, rev F. The cast iron insert as pre-machined is given in drawing SKB 00004-122, rev D. The test gauge for the dimensional test of the openings is given, for information, in drawing SKB TEST 00002, rev B.

The steel profile cassette assembly and the details of the fixing attachments can be modified according to engineering expertise. Also, the structure of the dimensional test gauge can be modified for better practicability.

Technical specification for profiles in the steel section cassette is given in SKB technical specification no KTS022, rev 1. The specification for the steel section cassette is given in KTS021, rev 3. And finally the specification for the nodular cast iron EN1563 insert is given in KTS011, rev 3.

Procedure instructions are given for “requirements on 1) quality plan, 2) manufacturing and inspection plan”, for “identification of canister components”, for “control of inspection, measuring and test equipment” in documents: KT 0704, rev 4, KT 0705, rev 4, KT 0801, rev 2, KT 1102, rev 3, and KT 1103, rev 3.

In addition, due to earlier experience of test manufacture of this type of insert in the foundry, some additional destructive material testing was specified according to specification KTS011, paragraph 6.2 for three sections of the cast; top, 500 mm below the top and bottom.

### 3 PREPARING THE CASSETTE AND MOULD MANUFACTURE

The steel profile cassette was manufactured at TTP-Yhtiöt Oy, a subcontractor to the Jyväskylä foundry. Therefore, a detailed stepwise procedure plan was made to assure the demanding manufacture and control sequence including detailed documentation.

The square steel tubes used for the cassette were made of Rautaruukki cold-deformed and welded tubular profile. The steel quality was S355J2H, SI/B, -40 C. The root of the weld is ground and the seam is also ultrasonic-controlled during tube manufacture. The mechanical properties of the tube are:  $R_{p0.2}$  474 MPa,  $R_m$  530 MPa,  $A_5$  24% and Charpy V test averaged 245 J at -40 C. In Figure 1 the cassette can be seen in its welded condition.

As a special request, the outside corner radius of the square tube was controlled. The radius should be according to EN 10219 for square tubular products  $2.5 \times T$ , when the thickness  $T$  is between 6 to 10 mm. The measured radius was typically 27 mm. This value was controlled due to the fact that this radius has a remarkable effect on the stress concentration that, in turn, has an effect on the load bearing capacity of the insert.



*Figure 1. Steel cassette as welded.*

The straightness of the square tubes was controlled before welding with a gauge and with a string wire. After assemblage the steel rack form and straightness was again controlled. The openings were gauged successfully with the 156 mm gauge, see Figure 2. The bottom end flatness and perpendicularity was controlled. The result was acceptable and the allowable inaccuracy was 2 mm. The square profiles were welded together equidistantly in 8 sections of the length.



**Figure 2.** Control of straightness of the square tubes with a gauge.

After assemblage the steel rack was first cleaned (stained) by KS-SINKKI Oy in pickling tank (in hydrochloric acid for 4 to 10 hours) and then, after flushing, drying and transportation to foundry. This time the casting in the foundry was scheduled so close to the delivery of the steel rack that it was not needed to be sand blasted before casting.

The construction of the mould can be seen in the photographs in Figures 3 to 11. The square tubes of the rack were filled with FuBK30 furfuran sand to avoid bending of the flat walls of the tubes inwards. CO<sub>2</sub> was used as filling gas and the long furfuran sand filled tubes were equipped with gas exhaust strings, too. All the mould was pre-heated for a couple of days in +70 to +80 C.



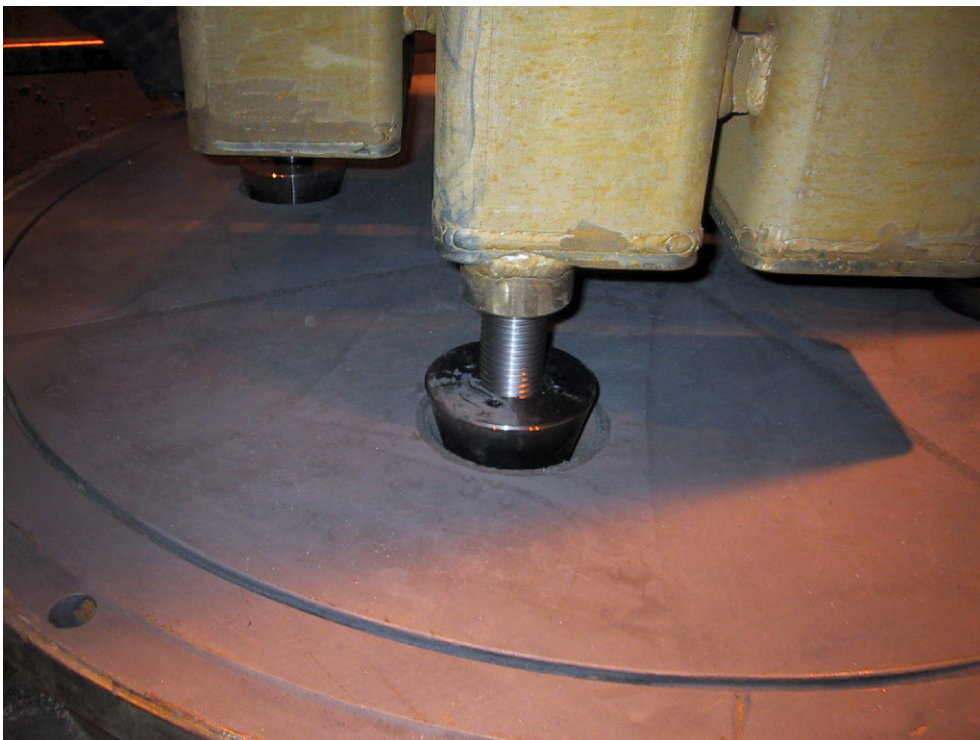
*Figure 3. Bottom of the mould is formed from a chill structure (steel plate).*



*Figure 4. Bottom of the mould as prepared.*



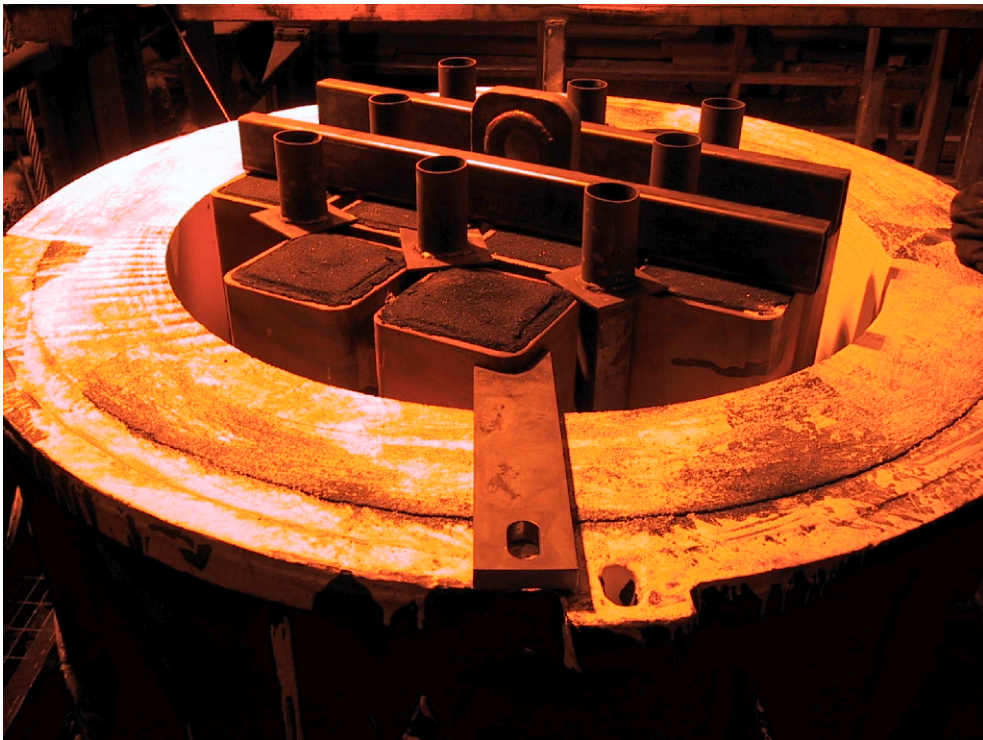
*Figure 5. Steel cassette is installed as stained condition into the mould.*



*Figure 6. Steel cassette is set straight inside the mould by the four supporting screws.*



*Figure 7. Steel cassette is supplied with gas exhaust strings.*



*Figure 8. Steel cassette is then filled with furfuran sand and the top of the cassette is supported with guides.*



**Figure 9.** Pouring basin from below. Some 100 mm gap is reserved for cassette expansion upwards during casting.



**Figure 10.** Pouring basin for the melt iron seen from above. See openings in the basin bottom covered by square steel plates. Photo Jussi Heinonen.



*Figure 11. The mould with equipments is ready for casting.*

#### 4 CASTING

Casting of the insert took place on June 23 in 2004. The liquid metal temperature was 1435 C, when poured from the foundry furnace. Iron type was GJS 404 with the exception of Ni, which was adjusted to range of 0.18 to 0.22 %. The additive treatment for nodulizing was FeSiMg 5501, 12 kg/ton. The time between the melt pouring from the furnace and casting was about 10 minutes. The casting temperature of the iron melt was 1350 C. The time needed for filling the mould was 75 sec. Casting event can be generally seen in Figures 12-13.

The casting process was documented according to requirements of KTS011 specification, paragraph 4.



*Figure 12. Beginning of casting the canister insert. Photo Jussi Heinonen.*



*Figure 13. In the end of casting some overflow of melt iron was happening due to oversized charge.*

## 5 CLEANING AND CUTTING THE CAST

After cooling down the cast was lifted up from the casting pit and cleaned. Lifting is seen in Figure 14. The inside of the cassette tubes were first emptied and then sand blasted. In this phase there were no visible indications of deviations in any part of the cast.

The excessive top part of the cast, some 600 mm, was cut off.



*Figure 14.* After cooling down the cast block was lifted up from the casting pit and cleaned.

## 6 DIMENSIONAL CONTROL BEFORE MACHINING

The shape and size was controlled after cleaning and cutting off the excessive top part of the cast. Also a slice for material testing was cut from the bottom end by the large band saw of Metso Jyväskylä Foundry.

Length was acceptable. The cast had intentional excessive length in both ends. The outside diameter had a working margin of 20 mm. Only a very low eccentricity (5 mm) was detected in the top part of the cast. The working marginal in the diameter covers the detected eccentricity without any problem.

After cleaning and cutting the cast openings were gauged according to the requirements of the specification with 152 mm gauge. The gauge travelled through all the 12 openings without being stuck.

Due to experience from some other foundries, the depths of the cassette openings were measured. The four openings closest to the centre of the insert were 3 mm lower than the other 8 openings. This means that the bottom plates of the four innermost cassette tubes had yielded slightly during casting. Metso Jyväskylä Foundry has used 15 mm steel plates (instead of 12 mm) in the cassette bottom. Probably, this is why the bottom plate yielding has been much lower than in some other cast tests. These cassette bottom plate irregularities shall be added to the objects to be inspected in every insert (quality control plan) and acceptance limits for irregularity shall be defined.

In general, the dimensional tests of the cast were passed.

## **7 MACHINING AND DIMENSIONAL CONTROL AFTER MACHINING**

The rough turning of the cast was made in the Metso Paper workshop in Jyväskylä. The turning lathe is usually used for machining of paper mill cylinders. The cast was machined direct to final main dimensions.

The outer cylindrical surface including the slightly conical part in the bottom corner and the planar bottom was machined with a turning lathe. The socket for the insert lid was made by circular milling machine. Due to lack of suitable special tools, the cone shape edge of the socket was not milled.

After machining in the turning lathe the dimensions of the cast were controlled. The diameter was in tolerance  $D949 +0.5/-0.0$  mm and the length  $4573 +0.0/-0.5$  mm. The top end of the cast was centralised before machining according to the square openings and thus the outer surface eccentricity was totally vanished during machining. The integral bottom thickness was 65 mm including the thickness of the bottom plates in the openings.

## 8 MATERIAL TESTING

The standard type testing was made according to requirements of EN 1563. The results are as shown in Table 1 and 2. Material samples were from cast-on test pieces at both top and bottom. No hardness test was made.

*Table 1. Chemical composition of the cast material.*

Chemical composition (%)									
C	Si	Mn	S	P	Mg	Cr	Ni	Mo	Cu
3.50	2.22	0.38	0.007	0.02	0.05	0.05	0.02	0.005	0.12

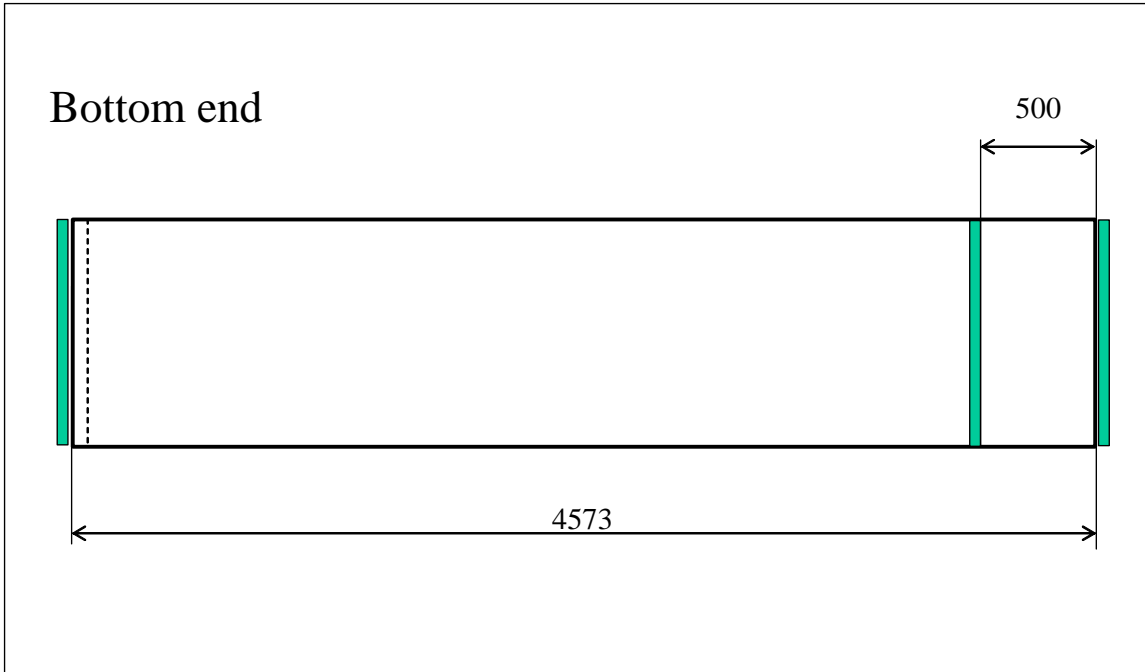
*Table 2. Mechanical properties according to EN 1563 Type II test.*

Mechanical properties			
	Yield strength MPa	Tensile strength MPa	Elongation %
Measured (top)	258	392	24.9
Measured (bottom)	264	391	9.3
Standard requirement	240	370	11

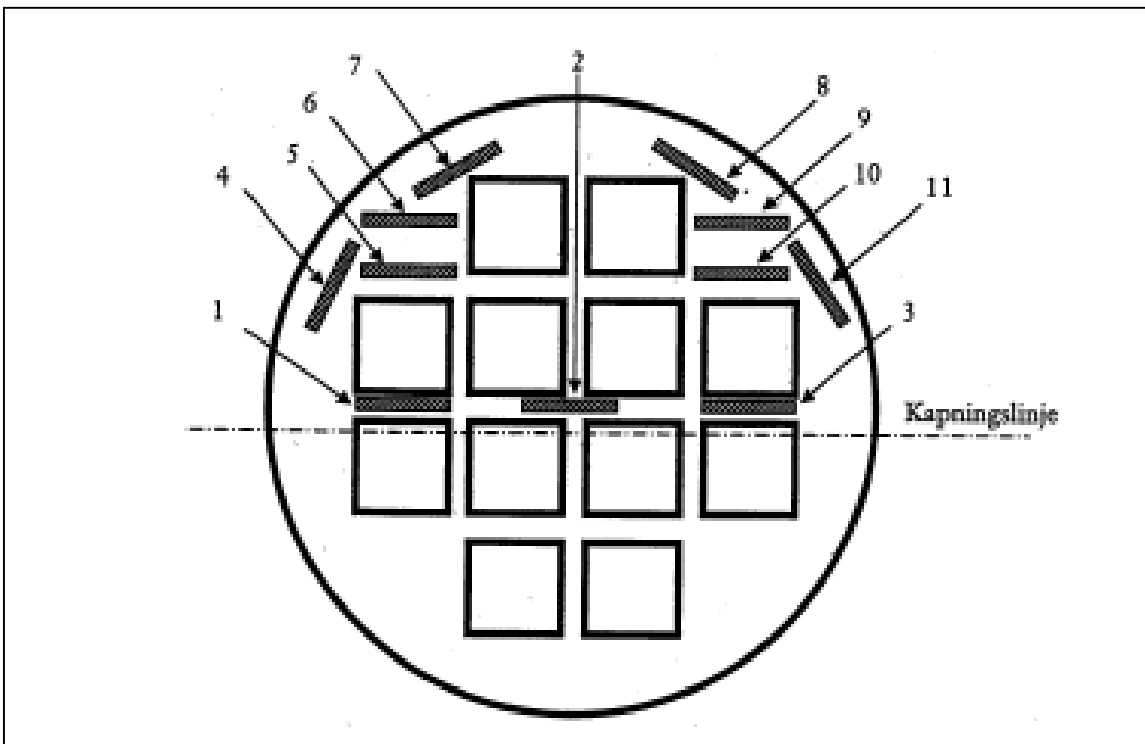
In addition to the normal cast-on material samples, there was a plan to make destructive sampling also from the cast body itself. Before and after machining the insert was cut into pieces according to Figure 15.

A microstructure test (metallography) was made from some of the samples taken from the top and bottom slice of the cast body, itself. The location of numbered samples can be detected according to Figure 16. The result is shown in Figures 17 and 18. The nodularization, shape and size, and the matrix structure are good and according to specification. However, the ductility according to tensile testing was too low in samples taken from top part of the cast, see values in Figure 17. Low ductility yielded to low ultimate strength (R<sub>m</sub>) in some cases. The strength and ductility results in bottom part were excellent, see Figure 18. All the tensile test data is reported in Table 3.

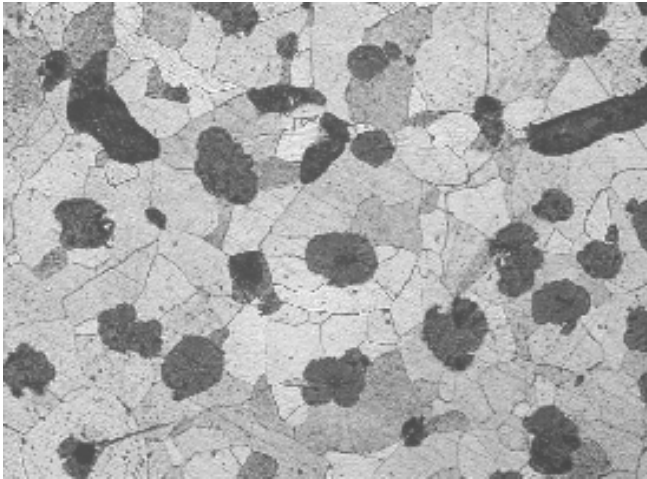
A remarkable confusion can be seen in the measured tensile test results between cast-on samples and the samples from inside the cast body. The elongation to rupture (A<sub>5</sub>) was, without exception, much higher in samples taken from the top part of the cast itself, whereas the results of the cast-on samples were on the contrary.



**Figure 15.** Cutting of the slices for the destructive material testing. The green slices were cut off and a set of material testing samples were made from each of the slices.



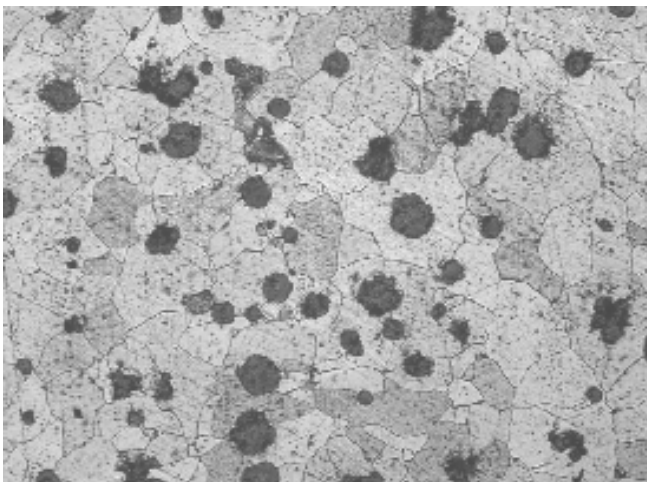
**Figure 16.** Numbering of the samples taken from each material slice in Figure 15.



Sample V1 (top level)

Nodule types V-VI ~90 %  
size 5  
ferrite 95 %  
perlite 5 %

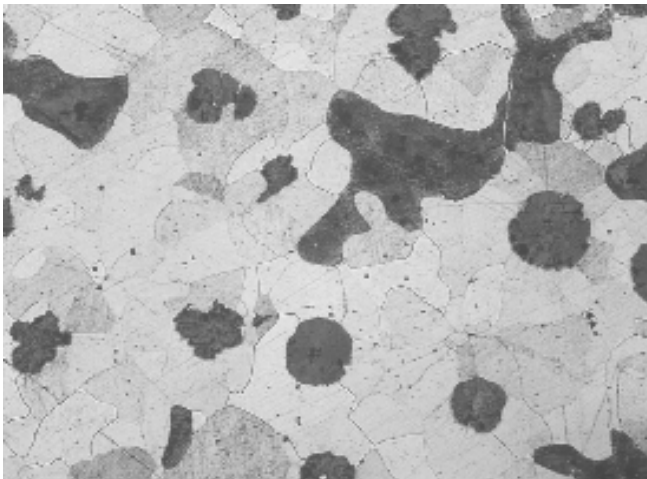
$R_{p0.2}$  267 MPa  
Rm 381 MPa  
A5 7.4 %



Sample V2 (top level)

Nodule types V-VI ~90 %  
size 6  
ferrite 97 %  
perlite 2 %  
sementite 1 %

$R_{p0.2}$  259 MPa  
Rm 370 MPa  
A5 6.1 %

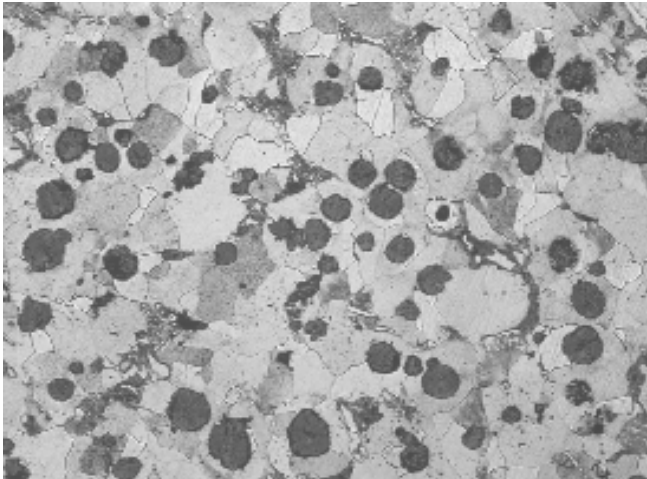


Sample V3 (top level)

Nodule types V-VI ~80 %  
size 4  
ferrite 90 %  
perlite 10 %

$R_{p0.2}$  265 MPa  
Rm 335 MPa  
A5 2.4 %

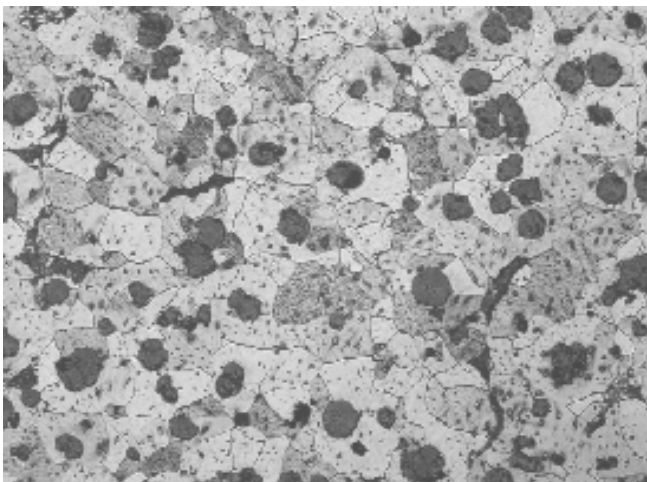
**Figure 17.** Microscope view of the ground cast surface. Samples are from the insert at top level, positions according to samples V1, V2 and V3.



Sample P9 (bottom level)

Nodule types V-VI ~98 %  
 size 6  
 ferrite 90 %  
 perlite 2 %  
 sementite 8 %

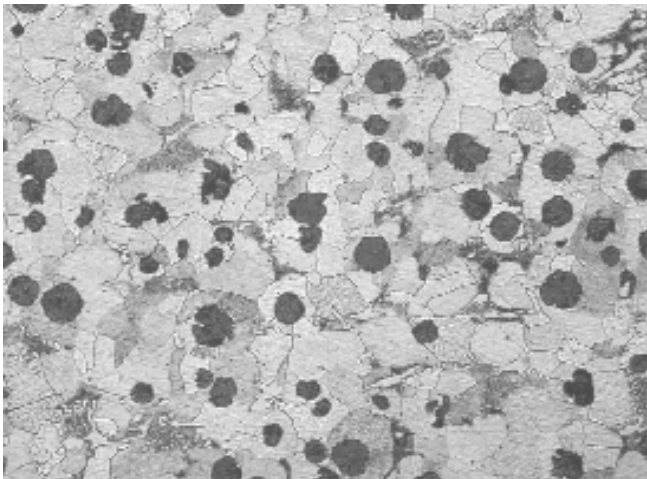
$R_{p0.2}$  275 MPa  
 $R_m$  439 MPa  
 A5 19.8 %



Sample P10 (bottom level)

Nodule types V-VI ~98 %  
 size 6  
 ferrite 94 %  
 perlite 3 %  
 sementite 3 %

$R_{p0.2}$  274 MPa  
 $R_m$  434 MPa  
 A5 19.7 %



Sample P11 (bottom level)

Nodule types V-VI ~98 %  
 size 6  
 ferrite 94 %  
 perlite 1 %  
 sementite 5 %

$R_{p0.2}$  289 MPa  
 $R_m$  458 MPa  
 A5 14.3 %

**Figure 18.** Microscope view of the ground cast surface. Samples are from the insert at bottom level, positions according to samples P9, P10 and P11.

**Table 3.** Mechanical testing result from test slices at top, 500 mm from top and at bottom in Figure 15. Samples are taken from the destructed cast body. Red figures below specified value.

Location	Mechanical properties		
	Bottom / 500 mm from top / top		
Numbers according to Fig. 16	Yield strength MPa	Tensile strength MPa	Elongation %
1	-/-/267	-/-/381	-/-/7.4
2	-/249/259	-/331/370	-/3.0/6.1
3	270/251/265	421/344/335	21.1/4.0/2.4
4	-/249/279	-/314/377	-/3.0/3.7
5	-/-/288	-/-/416	-/-/4.4
6	273/-/287	429/-/423	21.1/-/6.8
7	283/-/264	448/-/336	15.2/-/3.0
8	-/-/285	-/-/410	-/-/5.2
9	275/-/293	439/-/407	19.8/-/3.9
10	274/-/302	434/-/443	19.7/-/5.4
11	289/-/275	458/-/360	14.3/-/3.8
Reference values for EN-GJS-400-15U, t=60-200 mm	240	370	11 (New req. 7%)

Ultrasonic testing was made for the block after machining. The outer circumference of the insert was tested with ultrasonic equipment. The reference indication was a D3 mm flat bottom hole in the back wall of the reference block. A probe with 2 MHz frequency was used. No indication above reference was detected.

## 9 SUMMARY

The result of the insert cast trial fulfilled all the dimensional and shape requirements but the material mechanical properties and metallurgical structure of the cast material did not satisfy the requirements of the specification.

The measured ultimate strength and elongation at rupture were lower than specified in the upper part of the cast. The reason for this was revealed in the metallurgical investigation of the cast material. The cast contained slag (dross).

Avoiding the dross formation will be the most demanding challenge of the forthcoming development of the cast procedure.