Technical Report

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Status report, canister fabrication

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Summary

The report gives an account of the development of material and fabrication technology for copper canisters with cast inserts during the period from 2000 until the start of 2004. The engineering design of the canister and the choice of materials in the constituent components described in previous status reports have not been significantly changed. In the reference canister, the thickness of the copper shell is 50 mm. Fabrication of individual components with a thinner copper thickness is done for the purpose of gaining experience and evaluating fabrication and inspection methods for such canisters.

As a part of the development of cast inserts, computer simulations of the casting processes and techniques used at the foundries have been performed for the purpose of optimizing the material properties. These properties have been evaluated by extensive tensile testing and metallographic inspection of test material taken from discs cut at different points along the length of the inserts. The testing results exhibit a relatively large spread. Low elongation values in certain tensile test specimens are due to the presence of poorly formed graphite, porosities, slag or other casting defects. It is concluded in the report that it will not be possible to avoid some presence of observed defects in castings of this size. In the deep repository, the inserts will be exposed to compressive loading and the observed defects are not critical for strength. An analysis of the strength of the inserts and formulation of relevant material requirements must be based on a statistical approach with probabilistic calculations. This work has been initiated and will be concluded during 2004. An initial verifying compression test of a canister in an isostatic press has indicated considerable overstrength in the structure.

Seamless copper tubes are fabricated by means of three methods: extrusion, pierce and draw processing, and forging. It can be concluded that extrusion tests have revealed a microstructure and mechanical properties that satisfy stipulated requirements. The method is suitable for serial production. Development of pierce and draw processing is aimed at being able to fabricate copper tubes with an integral bottom. The results to date indicate that this may be possible. Like extrusion, pierce and draw processing can also be used to fabricate tubes without bottoms. Single tubes have been fabricated by forging. Forging can probably also be developed into a workable production method.

The technology for forging lids and bottoms of copper has been developed and is producing satisfactory results.

An important part of the quality assurance of canister fabrication is the development of technology and procedures for nondestructive testing by means of ultrasound. The work is being pursued in cooperation with the relevant suppliers. Supplementary investigations are being conducted at the Canister Laboratory. Acceptance criteria must be specified for both superficial defects and discontinuities inside the material. The possibilities of determining material parameters in both copper and nodular iron by means of ultrasound are being studied. In copper the grain size is of interest, and in nodular iron the nodularity of the graphite.

The account given in the report shows that fabrication methods that can be developed for use in serial production are available for all canister parts. A plan for continued work during the next few years has been compiled in the report.

Contents

1 Introduction

Over the past few years, development of fabrication technology for copper canisters and cast inserts has continued in accordance with the programme described in RD&D 2001 /1/. The viewpoints on RD&D 2001 offered by the Swedish Nuclear Power Inspectorate (SKI), the Swedish Radiation Protection Authority (SSI) and the Swedish National Council for Nuclear Waste (KASAM) have been taken into account in the planning of the work. Results up until August 2001 have been presented in two previous reports, /2/ and /3/. It was concluded in reference /3/ that fabrication methods are available for all canister components and that these methods can probably be developed for use in serial production. An outline of continued work on various detailed issues was also compiled in reference /3/, based on results obtained at that point and the viewpoints of the regulatory authorities. SKI, for example, has stated that prior to the time of a permit application for an encapsulation plant, SKB must have demonstrated that methods for fabrication and inspection are available and are suitable for serial production. This means that a sufficiently large number of canisters must have been fabricated and inspected and shown to satisfy stipulated requirements.

The fundamental design of the canister described in the references /1–3/ has not changed, see Figure 1-1. The canister consists of a pressure-bearing insert of nodular iron with a steel lid. The insert contains channels for the fuel assemblies, 12 in the BWR version and 4 in the PWR version. The insert is surrounded by an outer corrosion barrier of copper. No significant changes in the material requirements for the insert and copper shell have been made since the preceding status report. Current technical specifications for copper and nodular iron are found in this report as Appendices 2–4.

50 mm copper

Estimated weight (kg):

Copper canister	7,400
Insert	13,600
Fuel assemblies (BWR)	3,600
Total	24,600

Figure 1-1. Dimensions and weights of canister with 50 mm copper shell.

In the reference canister, the thickness of the copper shell is set at 50 mm. In both RD&D 1998 and RD&D 2001, SKB has stated that 30 mm thickness of the copper shell is sufficient from both a corrosion viewpoint and with reference to other design premises. When it comes to fabrication, sealing and inspection methods, a thinner copper shell has both advantages and disadvantages. The work of testing of fabrication methods and optimization of the detailed canister design is focused on a copper thickness of 50 mm. Single copper tubes with a wall thickness of both 30 and 40 mm have been trial-fabricated for the purpose of gaining experience and evaluating fabrication and inspection methods for such canisters.

All fabrication methods described in the preceding report, reference /3/, are still being considered. Preliminary trials with yet another method for fabrication of seamless tubes, forging, have been initiated.

In parallel with development and trial fabrication at various suppliers, cooperation has continued with institutes of technology and universities. Computer simulations and trials on laboratory scale provide knowledge that contributes to an optimization of material specifications and fabrication technology.

Collaboration has been initiated with Posiva Oy in Finland. The design premises for the canisters are essentially the same, which has led to essentially the same canister design and material requirements. A number of development projects concerning materials and fabrication technology are therefore being conducted in direct cooperation.

An overview of the latest results and issues regarding materials and fabrication technology was recently presented in a lecture at the international conference “Copper 2003”, 30 November–3 December 2003, in Santiago, Chile /4/.

Figure 1-2. *Copper tubes with welded bottom and cast insert.*

Table 1-1 shows how many components have been fabricated for the current canister design in Figure 1-1 up to the beginning of 2004. Some of these components have been used to assemble complete canisters. The number of complete canisters is also given in the table.

Table 1-1. Number of fabricated components and assembled canisters in early 2004.

Cast inserts of nodular iron	BWR version	19
	PWR version	1
Copper tubes	Roll-formed and longitudinally welded	13
	Extruded	15
	Pierced and drawn	4
	Forged	2
Forged blanks and finish-machined lids and bottoms		140
Steel lids for inserts		18
Complete assembled canisters		12

2 Materials technology

The engineering design of the canister and the choice of materials in the constituent components have been based on the design premises, references /5, 6/. The properties and function of the canister in the deep repository are determined by its engineering design and the material properties of its components. This chapter deals with materials technology aspects that can be related to the fabrication technology for canister components. Certain fundamental material properties, such as corrosion of copper and cast iron and creep deformation of copper, are not dealt with in this report. For information on these subjects, see RD&D 2001, reference /1/, and references /7–11/.

There are detailed technical specifications with precise material requirements for fabrication of all canister components. Technical specifications and procedures are included in the quality system that has been developed for canister fabrication. This is intended to cover the entire canister fabrication chain from material suppliers to finished canisters, and it is a part of SKB's quality system, certified to ISO 9001 and 14001. See Chapter 7 for further comments on this system. A list of technical specifications is provided in Appendix 1. Both technical specifications and procedures are updated continuously as a consequence of the ongoing development work.

This chapter deals with the materials technology aspects associated with fabrication of the canister's components, while Chapters 3 and 4 present the scope and results of trial fabrication.

2.1 Canister inserts

The canister insert is the pressure-bearing component in the canister and must meet the strength requirements that follow from this. In the deep repository the canisters will be exposed to a maximum external pressure estimated at 44 MPa under ice-age conditions.

The inserts are made of nodular cast iron with a primarily ferritic matrix structure. Cast iron is the generic term for iron-carbon alloys with more than about 2 percent (by weight) carbon. The cast irons used for fabrication normally have carbon contents in the range 2.5–4.0%. In one group of cast irons, carbon that is not bound in any other way is precipitated as free graphite when the molten iron cools and solidifies. The graphite can occur in different forms, and it is the form of the free graphite that gives different types of graphitic cast irons different properties. These types have been standardized and are shown in Figure 2-1.

Iron with graphite form I is called grey iron. Grey iron is the most widely manufactured cast metal and is used in many different contexts. Nodular iron with graphite form VI is also produced in large volumes. Components of the same or larger size as SKB's insert are produced in many foundries in both grey iron and nodular iron.

The form of the graphite has a great influence on the properties of the material. In grey iron, the flakes of graphite act as stress concentrators inside the material, and grey iron is therefore generally a brittle material. Nodular iron has a much higher strength and ductility than grey iron since the graphite is of nodular form. These strength properties, plus the fact that nodular iron has good casting properties and is easy to machine, explain why nodular iron has been chosen as the material in the inserts.

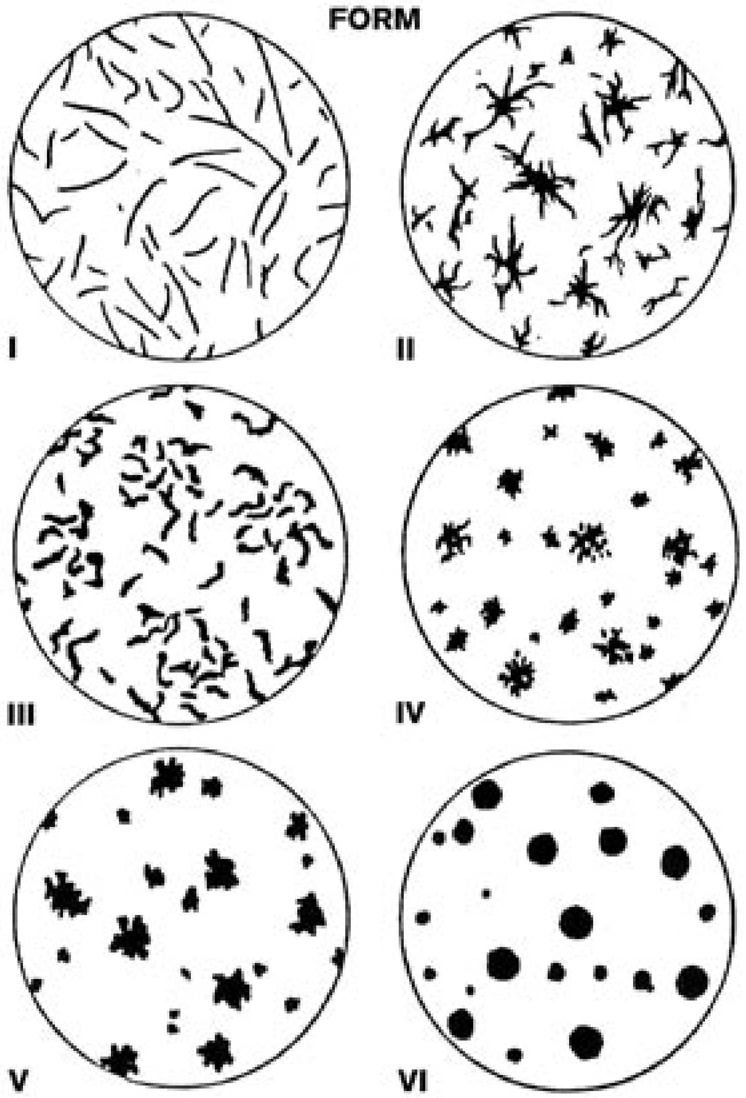


Figure 2-1. *Graphite forms in cast iron according to EN-ISO 945. The dominant graphite form in nodular cast iron is No. VI. (Nodular graphite.)*

The form, size and distribution of the graphite can be controlled by the addition of small quantities of elements to the melt. Magnesium is widely used in nodular iron, along with an “inoculant”, generally ferrosilicon. The properties of the cast iron can also be affected by different concentrations of such alloying elements as manganese, nickel, chromium and copper.

The mechanical properties of the cast iron are tested by tensile testing of test bars, which in the case of cast iron can be taken out in different ways. In this context we will differentiate between cast-on test bars and test bars made directly from a part of the casting. The latter of these alternatives is of course the most representative of the properties of the finished component. Cast-on test bars are obtained by providing suitable cavities in the mould wall so that test bodies of suitable size are obtained as projecting parts of the casting. One advantage is that cast-on test bodies can be sawn of off the component without damaging it. Test bars for tensile testing can then be made from these bodies. The cast-on test bodies harden and cool together with the insert and should therefore have a microstructure and properties equivalent to that of the cast iron in the finished product. The best agreement is obtained in the casting of small pieces.

A number of nodular irons are standardized in SS-EN 1563. The standard makes no requirements on chemical composition. But it does state that the graphite form shall essentially correspond to forms V and VI, and specified requirements are made on the mechanical properties of castings of different sizes. SKB's inserts represent a much thicker-walled casting than has been stipulated in this standard. However, the possibility is left open that specific material requirements on a given product can be agreed on with the supplier in each individual case. Based on this, SKB has prepared its own preliminary technical specification for cast inserts, KTS 011 in Appendix 4. The material requirements specified in KTS 011 can be briefly summarized as follows:

Material designation in EN 1563: EN-GJS-400-15U (Number EN-JS1072, SS 07 17-00)

The following requirements apply to specimens taken out anywhere in the insert:

Yield strength (0.2% elongation limit) $R_{p0.2}$: min 240 N/mm^2.

Tensile strength R_m: min 370 N/mm^2.

Elongation A: min 11%.

Microstructure (nodularity): At least 80% of the graphite shall be of forms V and VI in Figure 2-1. Graphite forms I–III shall not occur.

Nodule count: min 100 graphite nodules/mm^2 (Measured at 100x magnification).

These requirements on yield strength, tensile strength and elongation are specified in the standard for this nodular iron for components with a wall thickness in the range $60 < t \leq 200$ mm and apply to cast-on test bars. The range $60 < t \leq 200$ mm is the biggest wall thickness indicated in the standard. In the standard, the strength requirements diminish with increasing wall thickness, and SKB's inserts actually have a much greater wall thickness. This means it is very difficult to achieve these values in inserts, and particularly in specimens taken out of the insert. Exact material requirements that ensure that the inserts meet the design requirements will be determined when planned strength calculations, probabilistic analysis and verified compression tests according to the programme described below have been carried out.

Computer simulations have been done of the casting processes and casting techniques used at every foundry for the purpose of optimizing the material properties and reducing their variability. They are described in greater detail in Section 3.1. This has led to a better understanding of and improvements in parameters such as gating system, casting temperature and technique in the addition of the small quantities of certain substances that control the form of the graphite and its distribution in the finished insert.

During the development work, SKB studied material properties obtained in both cast-on test bars and discs cut from the insert itself. The inserts were cast with extra length so that a cut disc could be evaluated from the top of the insert. The extra length has made it possible to obtain full-length inserts even after removal of the disc. However, some inserts were cut up so that additional discs along the length of the inserts could be used for extensive material testing. Results of and comments on the material testing carried out are presented in Chapter 3.

2.2 Steel lids for inserts

The lids for the inserts are made from rolled steel plate. The fabrication requirements are specified in KTS 012, Appendix 5. The material must meet the requirements for structural steel S355J2G3 according to the standard SS-EN 10025. The strength requirements and chemical composition of this steel are shown in Tables 2-1 and 2-2. After machining, the thickness of the finished lid is 48 mm.

Table 2-1. Chemical composition of steel S355J2G3.

Composition Maximum values (%)	
C	0.20
Si	0.55
Mn	1.60
P	0.035
S	0.035

Table 2-2. Strength requirements for steel S355J2G3 in thicknesses corresponding to lids for inserts.

Properties	Thickness range (mm)	Value
Yield strength, R_{eH}	40–63	≥335 MPa
Tensile strength, R_m	3–100	490–630
Elongation, A_5	40–63	≥19%

According to KTS 012, similar steels that meet the requirements on yield strength and tensile strength may also be used. This means that the market availability of steel plate that meets these requirements is good. The fabrication of steel lids is also relatively simple. Some twenty lids for inserts have been fabricated so far.

2.3 Copper tubes, lids and bottoms

In order to meet the requirement on chemical resistance in the environment prevailing in the deep repository, copper has been chosen as a corrosion barrier. Copper is judged to have the necessary durability, as well as to have a minimal effect on other barriers in the deep repository. The fundamental requirement on corrosion resistance has led to the use of pure oxygen-free copper. The starting material used to fabricate canister tubes is semi-continuously cast round copper ingots with a diameter of about 850 mm, while the starting material used to fabricate lids and bottoms is continuously or semicontinuously cast round ingots with a diameter of 500 mm. In order to specify the requirements, SKB has developed two technical specifications. KTS 001, Appendix 2, contains specified requirements on the copper ingots to be used as starting material in the fabrication of the components, while KTS 002, Appendix 3, contains the requirements after hot-forming of copper tubes and blanks for lids and bottoms.

Figure 2-2. *Steel lid for insert and a cast insert. The steel lid is designed to be screwed onto the insert with a bolt in the centre. The lid also has a groove for an O-ring to seal against the inside of the insert.*

As is evident from KTS 001, SKB's special requirements on the material are such that there is no direct equivalent in Swedish or international standards. According to KTS 001, the material shall fulfil the requirements in the standard EN 1976:1988 for the grades Cu-OFE or CU-OF1, with the additional requirements 0<5 ppm, P 30–70 ppm, H<0.6 ppm and S<8 ppm. The reasons for these tougher requirements compared with international standard can be summarized as follows:

- For fabrication-related reasons, there must be a clearance of a mm or so between the insert and the copper shell. This means that the copper shell will be plastically deformed by up to 4% in the deep repository. This deformation takes place chiefly by creep. The material must have enough ductility to withstand this with good margin. Elements such as hydrogen and sulphur have an adverse effect on ductility and must be reduced to low concentrations. Phosphorus has been found to have a favourable effect on creep ductility and is therefore specified in KTS 001 to concentrations between 30 and 70 ppm.
- The material must be able to be welded by electron beam welding. The oxygen concentration has an adverse effect here and must be kept at a low level.

Methods under consideration for seamless tube fabrication are extrusion, pierce and draw processing and forging. Blanks for lids and bottoms are fabricated by forging. In all of these cases, the hot-forming temperature is around 700°C. Requirements on the copper components after hot forming are given in KTS 002. The requirements on microstructure and mechanical properties can be summarized as follows:

- Grain size <360 µm (average grain size).
- Elongation A 50 mm (RT–100°C) >40%.
- Elongation at creep rupture >10%.

Computer simulations of extrusion of copper tubes and forging of blanks for lids and bottoms have been carried out in a doctoral thesis project at KTH, reference /14/. The results have yielded greater knowledge concerning how the material is deformed by different forming methods and what conditions must be met to obtain a microstructure with acceptable grain size. For forging of lids and bottoms, the results have been able to be used for optimization of the forging dies. A number of forgings done with the improved technique have shown that blanks for lids and bottoms can now be produced with very satisfactory results.

Simulation of pierce and draw processing for the purpose of fabricating copper tubes with integral bottoms has been carried out by Outokumpu Poricopper Oy and Vallourec & Mannesmann Tubes. The results have been used in designing the hot-forming tools. Fabrication trials with pierce and draw processing have so far indicated that a sufficiently fine-grained microstructure can be obtained in the integral bottom, see Section 4.1.3. Continued optimization of forging dies and process parameters will be able to further improve the results.

Trial fabrication of copper tubes by forging at Scana Steel Björneborg AB has shown that the method gives an acceptable grain size. This method needs to be further developed by optimization of tool design and process parameters.

3 Results from fabrication of cast inserts

3.1 General

In the preceding status report /3/ it was concluded that material testing had yielded results with relatively wide variations.

Extensive material testing has been conducted on a number of cast inserts. Test bars for tensile testing and microstructure examination have been made from discs cut from different locations in the inserts. See examples of specimen locations in Figures 3-1 and 3-2.

SKB has found a relatively wide range of variation in material properties in several individual inserts. The greatest variation in tensile testing is found in values for elongation at rupture. The ductility of this type of cast iron is highly dependent on the microstructure of the graphite and the presence of material defects such as porosities in the casting. The nodularity of the graphite (roundness as in type VI in Figure 2-1) has varied in some inserts. Some presence of porosities and slag particles has also been found. This has been detected by both microscopy and ultrasound.

An analysis by the Swedish Foundry Association employing computer simulations of the casting technique at each individual foundry has indicated some improvements. This and the foundries' own assessments regarding process parameters has resulted in measures aimed at ensuring more uniform material properties. Some examples of calculations performed are shown in Figures 3-3 to 3-8.

Figure 3-1. *Discs cut from cast insert for material testing.*

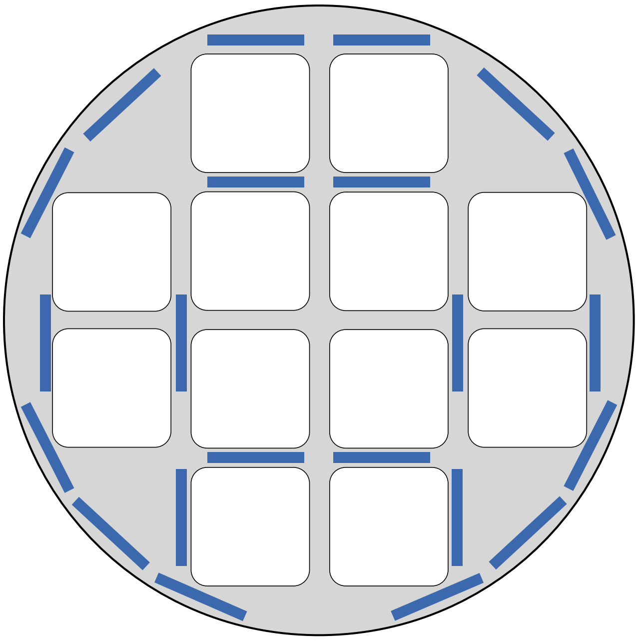


Figure 3-2. *Positions for test bars cut from disc from cast insert.*

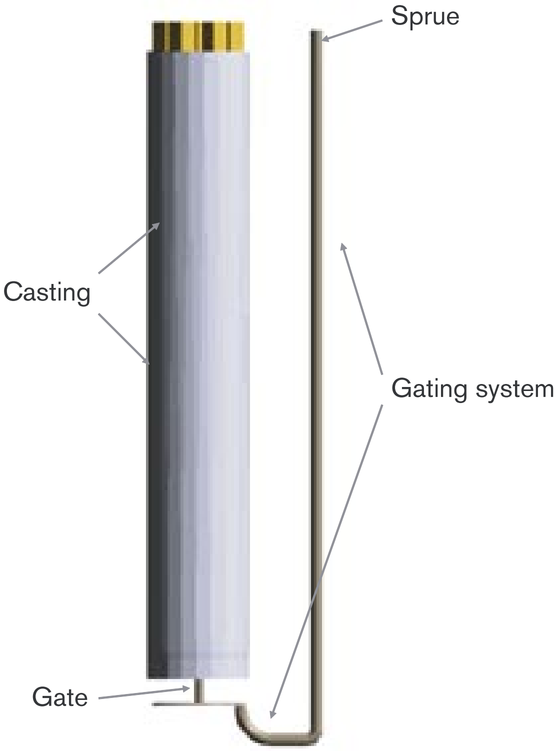


Figure 3-3. *Casting of inserts in nodular iron. Model of casting system for computer simulation.*

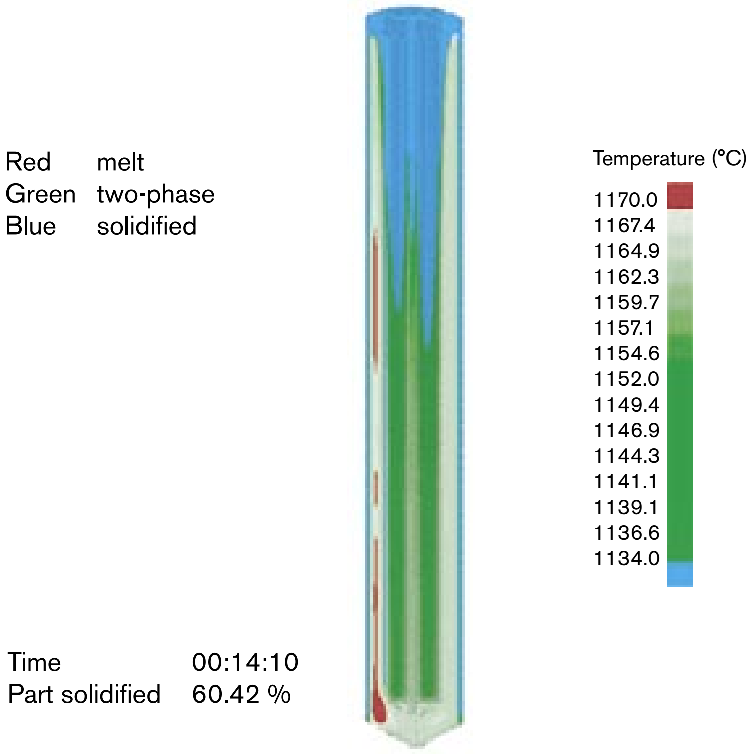


Figure 3-4. *Simulation of solidification process during casting of an insert. The inserts solidify from the top down. According to the simulation, the solidification time is about 3.5 hours.*

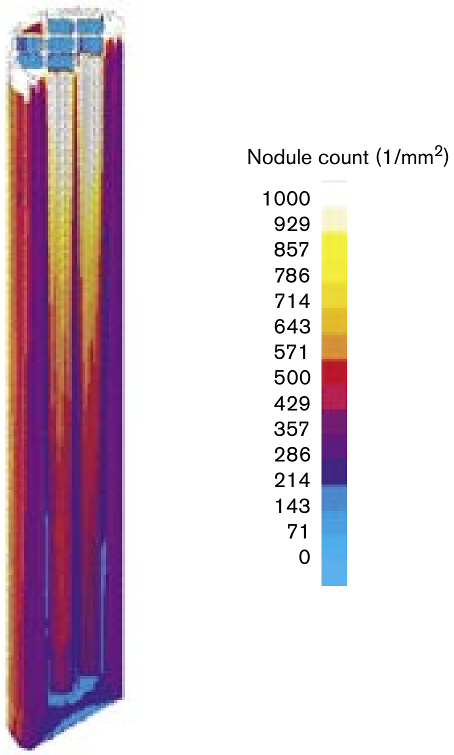


Figure 3-5. *Estimated nodule count in the insert. According to KTS 011 in Appendix 4, nodule count shall be at least 100 nodules/mm*^{2}.

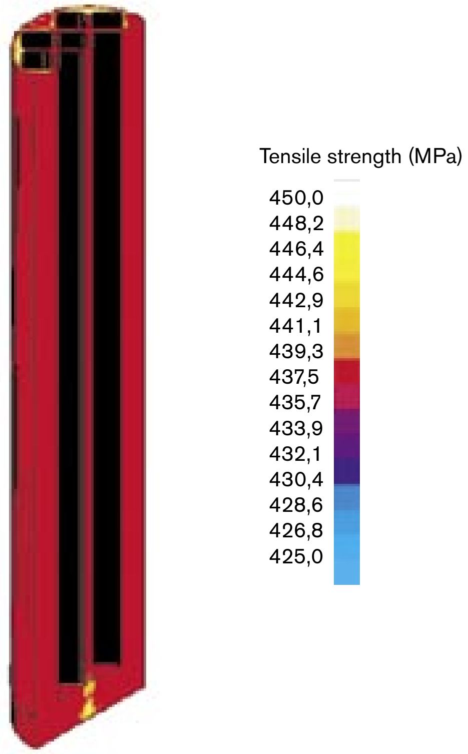


***Figure 3-6.** Estimated tensile strength in the insert. According to KTS 011, the tensile strength shall be at least 370 MPa.*

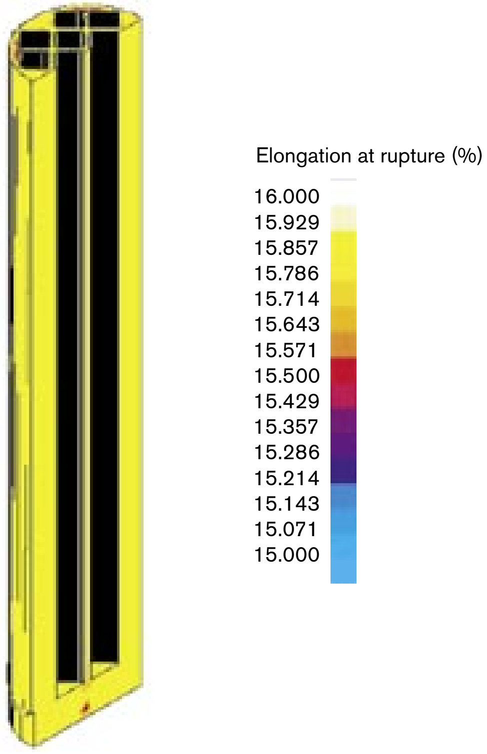


***Figure 3-7.** Estimated elongation at rupture in the insert. According to KTS 011, elongation shall be at least 11%.*

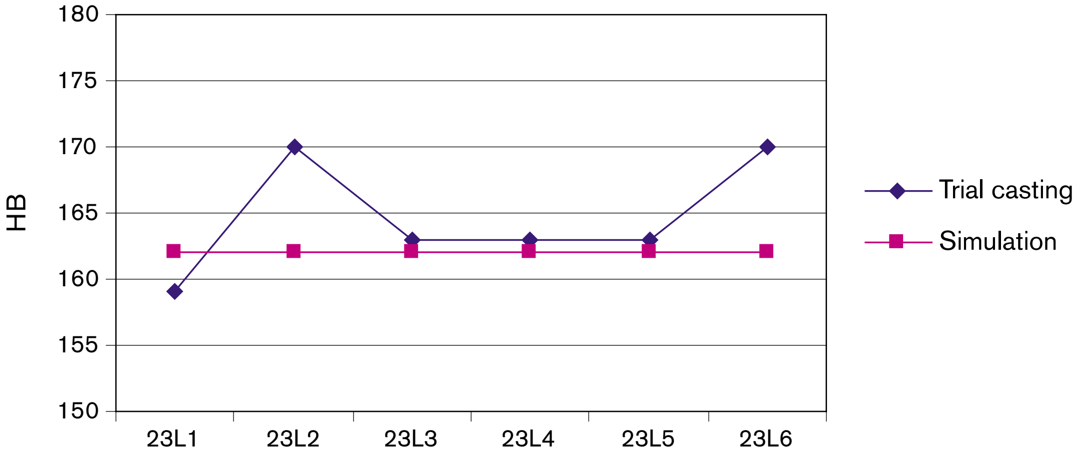


Figure 3-8. *Comparison between measured and estimated hardness of an insert.*

3.2 Results of trial castings

After completed analyses with subsequent remedial measures by the foundries, three inserts were cast and underwent extensive testing at the Swedish Foundry Association in Jönköping. The inserts were given the numbers I 24, I 25 and I 26, and they were cast at three different foundries in Sweden. The chemical compositions of these three inserts according to their delivery certificates are shown in Table 3-1.

Two discs were cut out of each insert for material testing, one from the top (T) and one from the bottom (B). Since the inserts had been cast with an extra-thick bottom, the bottom disc could be cut from the solid bottom. Blanks for tensile test bars were taken from each disc in accordance with the pattern shown in Figure 3-2. The square channels for fuel assemblies shown in Figure 3-2 are only found in the top disc. The results of the material testing are shown in Tables 3-2, 3-3 and 3-4.

The essential difference with regard to chemical analysis according to Table 3-1 lies in the concentrations of Si, Ni and Mn, which are highest in insert no. 126. According to the literature and the Swedish Foundry Association's calculations, this difference results in an approx. 58 MPa higher yield strength than in I25, Tables 3-4 and 3-3. If a comparison is also made for I24 with I25 as a base, the result is that I24 should have a yield strength about 21 MPa higher than I25. The measured difference agrees well with the calculated one, as shown in Tables 3-2 and 3-3.

Mn and Cu also improve the properties in the ferrite, but if their concentrations are too high pearlite is formed in the matrix. The Mn content in no. 126 is high, and in these specimens there is also a relatively high concentration of pearlite. An elevated pearlite concentration reduces the ductility of the material, but raises its yield strength and tensile strength.

In the previous status report, /3/, the results of tensile testing of test bars taken from 200 mm thick discs cut out of the tops of four inserts are reported. An improvement is found compared with the results then obtained in terms of yield strength, tensile strength and elongation. The results for insert I 25 are very close to the specified requirements. It can also be observed that the best material properties have been obtained in the lower part of the inserts. This is also what can be expected in such a large casting that has been cast upright in the mould. As was pointed out in Section 2.1, the requirements really apply to much thinner castings than the inserts. The requirement on elongation in tensile testing in particular is probably not realistic in these dimensions. In the continued work with probabilistic analysis (see Section 3.3), precise material requirements will be established based on the actual need.

Table 3-1.

Element	Insert no. I24	I25	I26
C	3.66	3.78	3.56
Si	2.31	2.08	2.39
Mn	0.15	0.21	0.52
P	0.026	0.006	0.03
S	0.009	0.008	0.010
Mg	0.050	0.035	0.063
Cr	0.03	No data	No data
Ni	0.27	0.50	0.73
Mo	0.01	No data	No data
Cu	0.11	No data	No data

Table 3-2. Test results insert I 24.

Property	Specification (KTS 011)	Top disc	Bottom disc	Comments
$R_{p0.2}$	Min 240 MPa			
Mean value		257	289	B = Good
1s		±18.1	±2.8	T = Wide variation
R_m	Min 370 MPa			
Mean value		299	408	B = Good
1s		±36.3	±7.1	T = Not good, wide variation
A_5	Min 11%			
Mean value		3.5	22.2	B = Good
1s		±1.6	±3.2	T = Not good
HBW				
Mean value		136	144	–
1s		±4.1	±3.0	Good
Nodularity 1)	Min 80%			
Mean value		90	90	Good
1s		±0	±0	Good
Min		90	90	Good
Max		90	90	–
Nodularity 2)	Min 100/mm^2			
Mean value		93	156	Good
1s		±87	±112	–
Min		35	90	T = Low
Max		255	415	Good
Pearlite fraction (%)				
Mean value		1.4	1	Good
Min		0	0	Good
Max		2	1	Good

1) Graphite form V and VI acc. to EN ISO 945

2) Number of nodules/mm^2

B = Bottom

T = Top

HBW = hardness Brinell

1s = standard deviation

Table 3-3. Test results insert I 25.

Property	Specification (KTS 011)	Top disc	Bottom disc	Comments
$R_{p0.2}$	Min 240 MPa			
Mean value		267	263	Good
1s		±2.0	±2.0	Good
R_m	Min 370 MPa			
Mean value		370	360	Slightly below requirement
1s		±9.0	± 4.2	Good
A_5	Min 11%			
Mean value		10.3	11.8	Slightly below requirement
1s		±3.4	±1.4	Good
HBW				
Mean value		139	133	–
1s		±3	±1	Good
Nodularity 1)	Min 80%			
Mean value		75	68	Not good
1s		±7	±7	–
Min		70	60	Not good
Max		90	80	–
Nodularity 2)	Min 100/mm^2			
Mean value		132	43	T = Good
1s		±103	±12	–
Min		40	30	Low
Max		315	60	T = Wide variation
Pearlite fraction (%)				
Mean value		1	1	Good
Min		0	0	Good
Max		3	5	Good

1) Graphite form V and VI acc. to EN ISO 945

2) Number of nodules/mm^2

A high value for elongation requires defect-free material with well-developed graphite nodules. Figure 3-9 shows such a microstructure in insert I 24. The test bar in question is taken from the bottom of the insert. Tensile testing and metallography gave the following values for this test bar: $R_{p0.2}$ = 292 MPa, R_m = 419 MPa, A = 24.6%, nodularity >90%, nodule count 345/mm^2 and the pearlite concentration was <1%. All values lie well beyond the requirements for this test bar.

The presence of pearlite in the microstructure, as well as poorly formed graphite, results in lower ductility. For the purpose of comparison with Figure 3-9, Figure 3-10 shows the microstructure of a test bar from the top of insert I 26. Besides the presence of pearlite, there are areas with poorly formed graphite, called "chunky graphite". Tensile testing and metallographic examination gave the following values for this test bar: $R_{p0.2}$ = 311 MPa, R_m = 359 MPa, A = 3.0%, nodularity about 60%, nodule count 140/mm^2 and the pearlite concentration was about 10%. It is known that problems with "chunky graphite" are sometimes encountered in the production of thick nodular iron castings. See reference /12/. To obtain further knowledge of this phenomenon, SKB will support and participate in a doctoral thesis project entitled "Improved graphite microstructure in thick-walled nodular cast iron" at the School of Engineering in Jönköping and the Swedish Foundry Association.

Some presence of defects of various kinds must be expected in thick castings. Figures 3-11 to 3-13 show examples of such defects. Even small defects such as in these examples lead to poorer values in tensile testing if they happen to be present in a test bar.

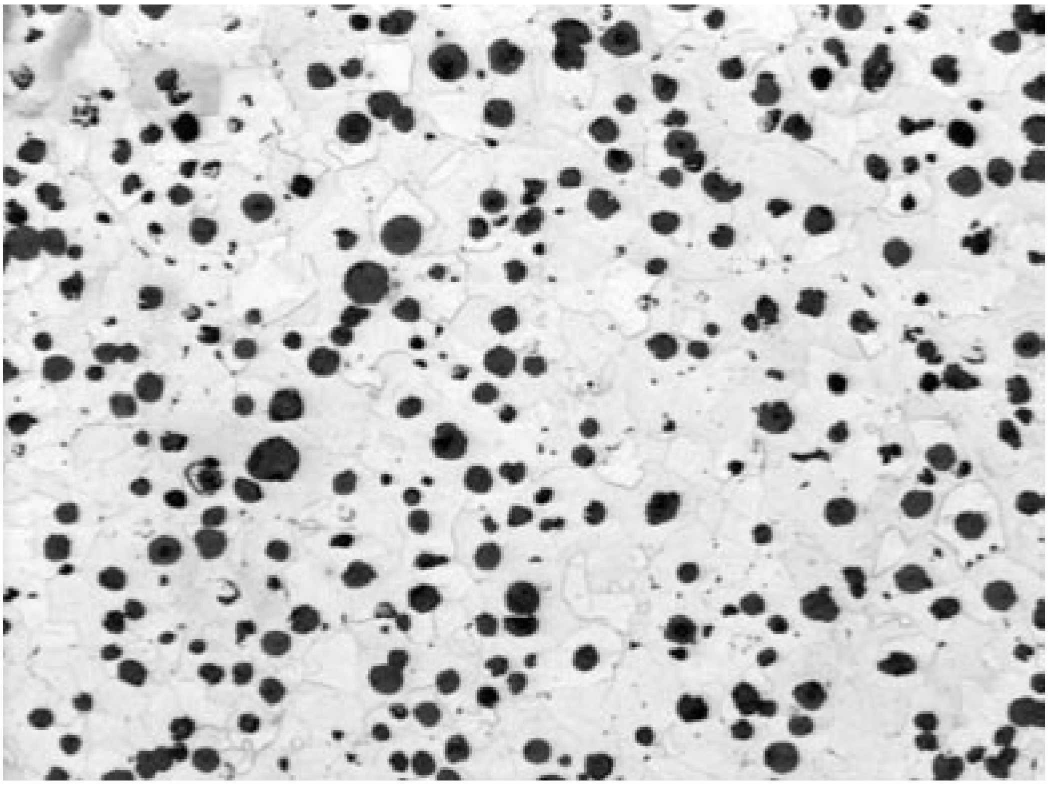


Figure 3-9. *Nodular graphite in cast iron with well-developed graphite nodules. (100x).*

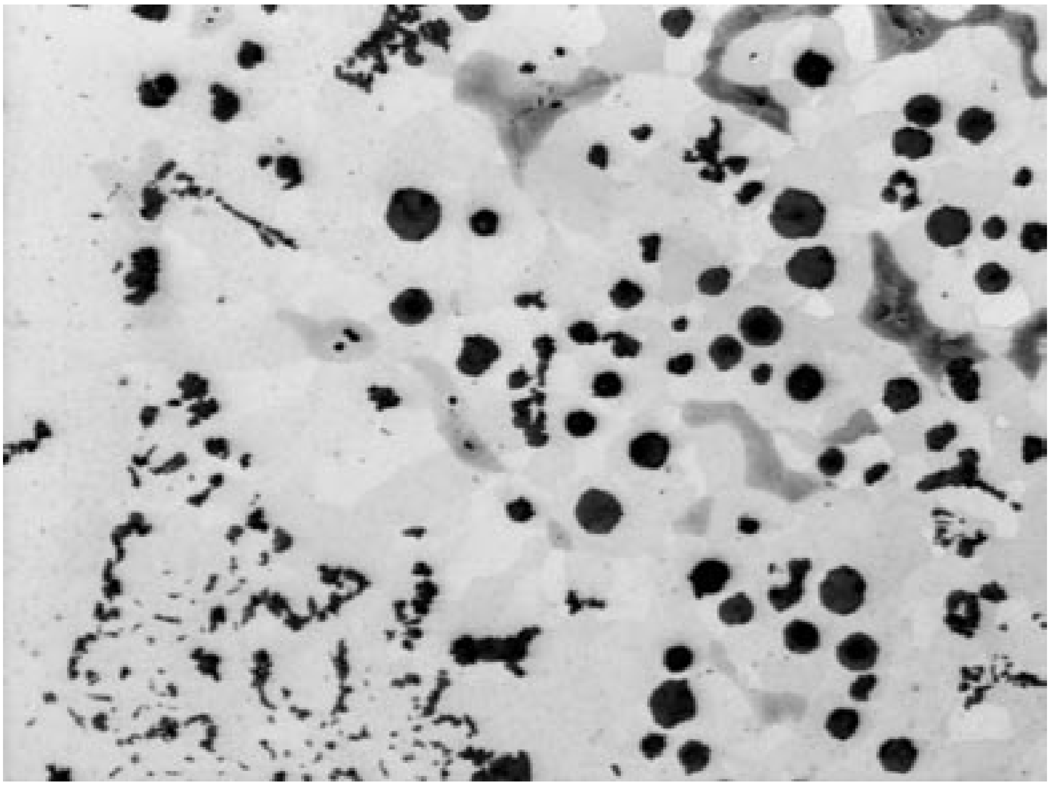


Figure 3-10. *Defective graphite microstructure, called "chunky graphite". (100x).*

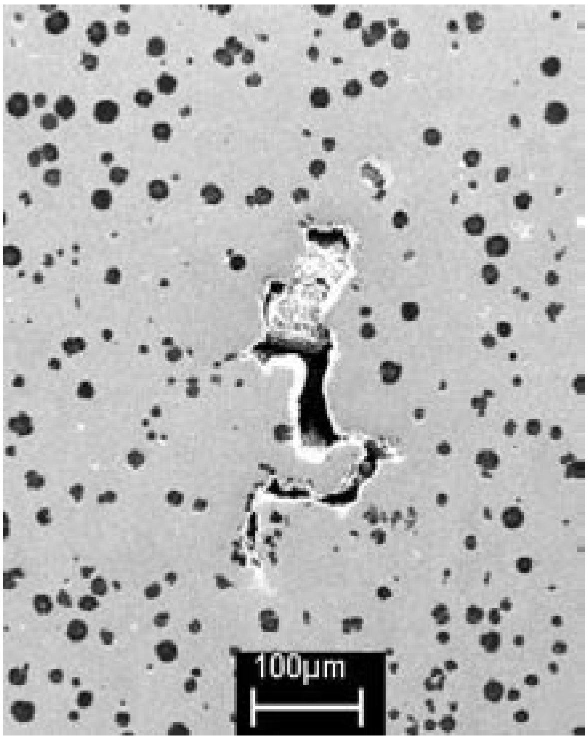


Figure 3-11. *A small porosity in a cast insert.*

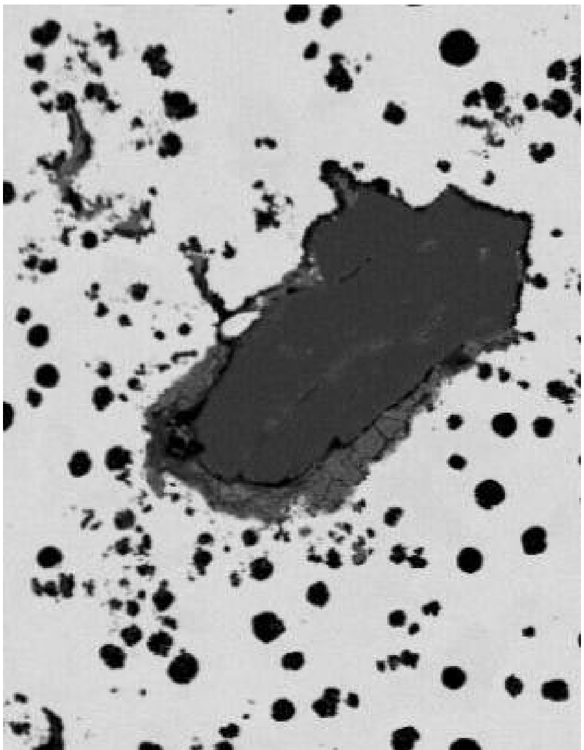


Figure 3-12. *Slag inclusion.*

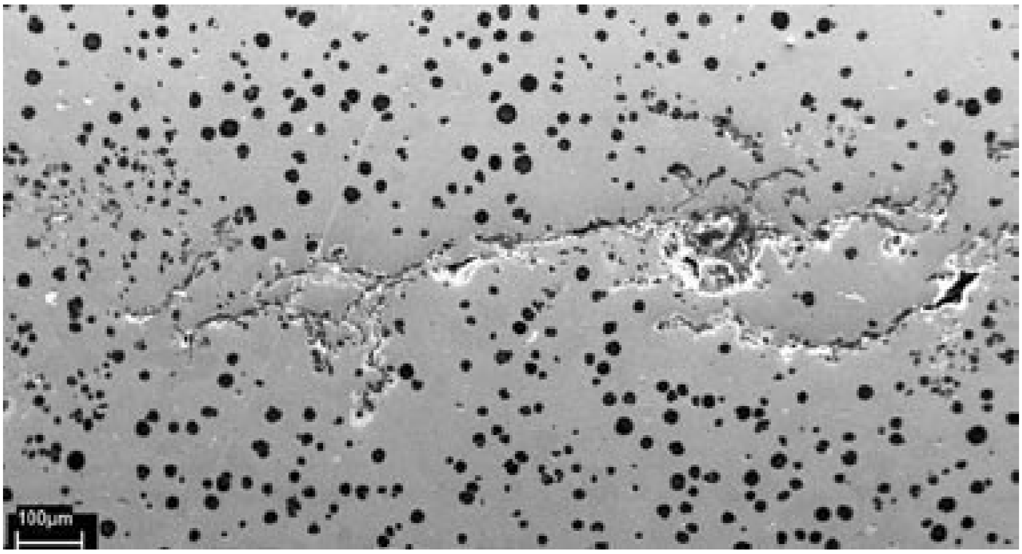


Figure 3-13. *Other casting defect.*

The results of the extensive material testing of cast inserts that has been carried out show that traditional tensile testing with test bars taken from different places in an insert will often produce results with a relatively wide range of variation. Individual test bars may give low values that do not represent the insert's actual strength. The principal stress on the inserts in the deep repository is furthermore compressive. Due to these factors, analysis of insert strength and formulation of a new specification of material requirements must be based on a statistical approach with probabilistic calculations. The beginning of this phase in the development of cast inserts is commented on in the next section.

3.3 Probabilistic analysis

An extensive development project has been started concerned with probabilistic analysis of canister strength. The participants include SKB, the Swedish Foundry Association, Ångpanneföreningen, the Royal Institute of Technology in Starting materialholm, the Joint Research Center (JRC) in the Netherlands, Det Norske Veritas and CSM Materialteknik AB. The three different inserts from different foundries described above (I 24, I 25 and I 26) are included in the study. A relatively large number of test bars are taken from different locations according to the pattern in Figure 3-2, including from other cut discs than those used in the material testing reported in Section 3.2. All test bars, as well as whole discs, are x-rayed to obtain values of the size and distribution of defects in the casting. The strength properties are evaluated by conventional tensile testing, but also by compression testing and fracture toughness testing. A fractographic analysis of the fracture surfaces is then performed, and the microstructure is examined metallographically. The large quantity of information will be used in a probabilistic analysis of the probability of failure, and a value will be obtained of the critical defect size at the stresses to which the canisters will be exposed.

Strength calculations employing finite element methods are also being carried out within the framework of the project. The results of this work will be presented in a separate report.

Verifying compression tests will be conducted in a cold isostatic press with water as the pressure medium, Figure 3-14. The test body, see Figure 3-15, consists of an insert, about 700 mm long but with full diameter. Both ends of the insert are covered by a screwed-on steel lid and enclosed in a 50 mm thick copper tube with lid and bottom of copper.

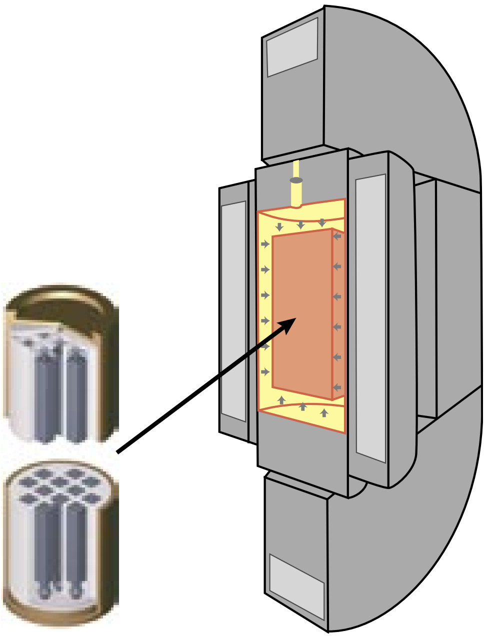


Figure 3-14. *Principle of compression testing in isostatic press.*

Figure 3-15. *Part of insert I 26 and part of a copper tube for compression testing.*

Aside from its length, the test body is thus very similar to a real copper canister. The first such test has been performed on a part of the insert I 26.

The relatively short length of the test body is due to the fact that a larger isostatic press could not be found. However, a strength calculation showed that the relatively short length of this test canister does not significantly affect the collapse load compared with a full-length canister. The canister was loaded in several steps up to 135 MPa. The canister had then been deformed about 20 mm, Figure 3-16, but the copper shell was still intact. Figure 3-17 shows the deformation of the nodular iron insert.

Figure 3-16. *The test canister after being exposed to an isostatic pressure of 135 MPa. The copper shell has been deformed locally about 20 mm. But the canister is still intact.*

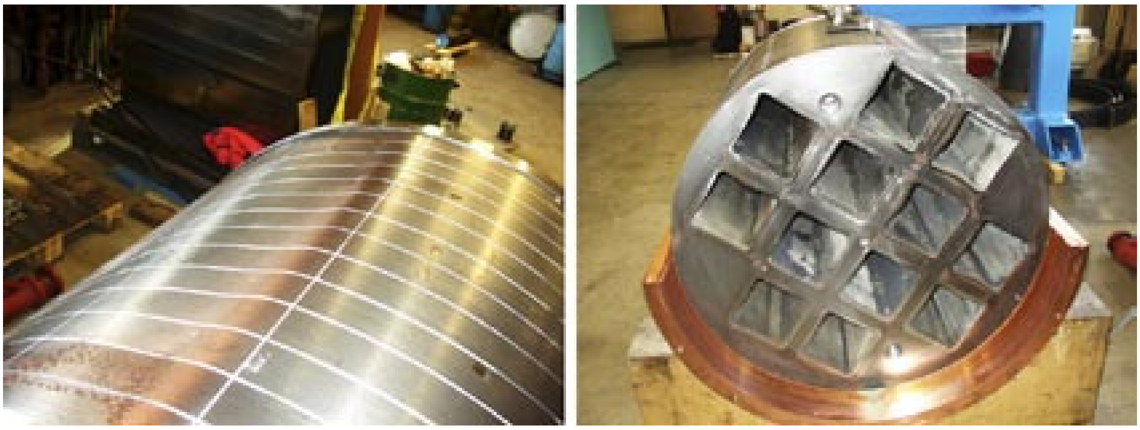


Figure 3-17, *A and B. The pictures show some local buckling of the insert. Figure B also shows that the square steel tubes that form the channels for the fuel assemblies have been deformed.*

The results from the first insert in the project, including test data from both material testing and the compression test, are currently being evaluated. These results will be reported separately.

However, it can be concluded that the compression test performed indicates considerable overstrength in the nodular iron inserts. This supports the argument in Section 3.2 that the requirements on the material can be modified.

4 Results from trial fabrication of copper components

4.1 Fabrication of copper tubes

The two previous status reports, /2/ and /3/, contain a relatively detailed description of methods for fabrication of tubes for copper canisters. Another method, forging of tubes, has now been added. The following methods are currently being considered:

- Extrusion.
- Pierce and draw processing.
- Forging.

In all three of these methods, the fabricated tubes are seamless, i.e. without longitudinal weld joints. All tubes have been made seamless since 1998. The requirements on fabricated copper components are given in the technical specification KTS 002, Appendix 3. The starting material in all three cases is cylindrical copper ingots.

4.1.1 Fabrication of ingots for seamless copper tubes

Since the most recent status report, SKB has fabricated 12 copper ingots at Outokumpu in cooperation with Posiva. Fabrication has taken place in accordance with an established quality plan. Material requirements, documentation requirements and delivery conditions are defined in KTS 001, Appendix 2.

Ingot manufacture can be described as semicontinuous casting with production of one ingot at a time. This means that each ingot must be cut at the top so that remains of defects that are always formed at the top of an ingot are removed. Since trial fabrication of tubes for 50 mm wall thickness has in some cases revealed difficulties in achieving tubes of sufficient length, as much as possible of the ingots has been used. The plant has technical limitations which prevents the fabrication of ingots larger than about 14 tonnes. The current opinion is that ingots of at least about 13.5 tonnes are required to fabricate tubes with integral bottoms by pierce and draw processing. The material yield in both ingot manufacture and pierce and draw processing can probably be optimized, however. (Copper ingots of less than 12 tonnes are required for tube fabrication by extrusion and forging.)

The challenge of producing ingots with a higher yield has been to control the process so that

- the oxygen concentration at the beginning of the ingot is not too high,
- centre cracks at the beginning of the ingot are reduced,
- the phosphorus content is controlled,
- the surface quality of ingots is satisfactory.

After casting, the first 10–30 cm of the ingot is cut away, since the process is not yet stable and the right chemical composition cannot be ensured.

One of the ingots was divided diametrically into two cylinder halves. One surface was polished and etched. Lessons were learned from the appearance of the solidification front and crack formation.

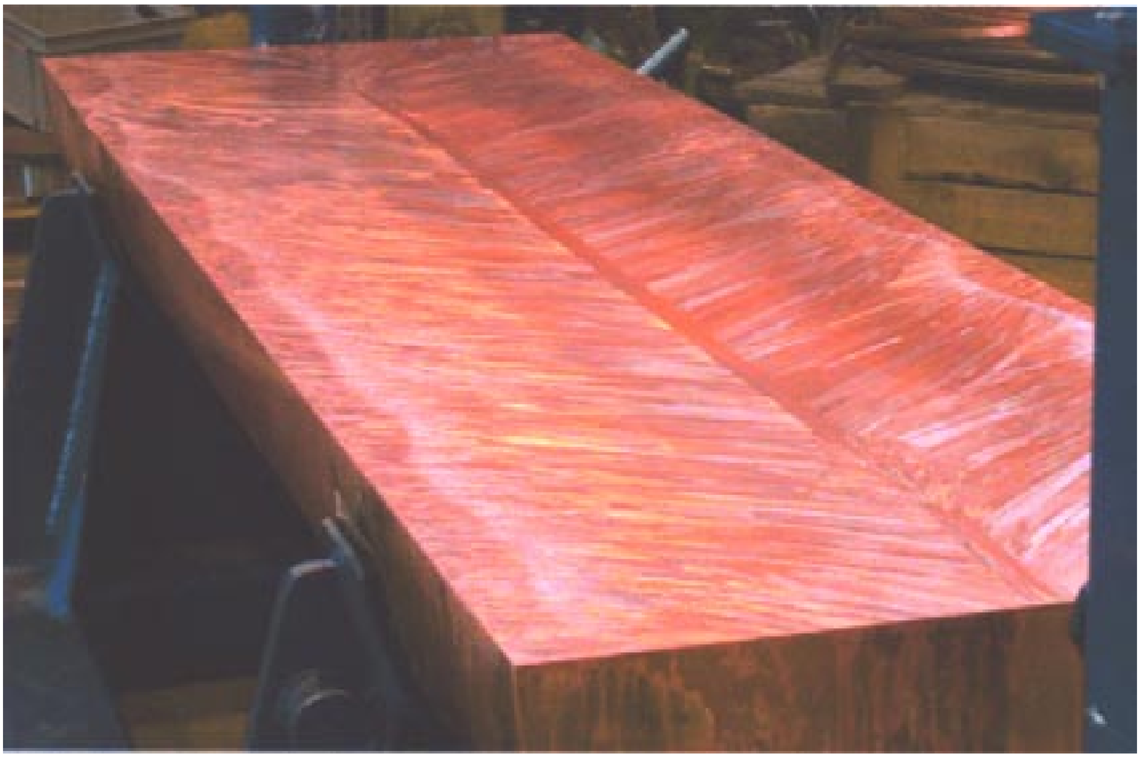


Figure 4-1. *Crystal structure in a divided copper ingot.*

Chemical analyses according to delivery certificates for ingots used for fabrication of the tubes dealt with in this report have been compiled in Table 4-1.

4.1.2 Extrusion of copper tubes

Five tubes have been fabricated by extrusion since the preceding status report. The doctoral project at KTH, /14/, has yielded greater knowledge of how the hot-forming parameters can be controlled to obtain the desired microstructure. Of the new tubes, T 25 was another trial fabrication of a tube intended for 40 mm wall thickness after finish machining. Other tubes – T 26, T 27 and T 31 – were for a 50 mm wall thickness. Table 4-2 shows microstructure and mechanical properties obtained for these tubes. The forming temperature in extrusion is about 700°C.

It can be concluded that the obtained microstructure and mechanical properties are approved and can be controlled by controlling the fabrication parameters. Extrusion is thereby a method that can be used for serial production of copper tubes. In the continued work, the methods for quality inspection, including NDT by ultrasound (see Chapter 6) and dimension measurement, will be developed. In addition, the straightening technique needs to be improved, as do procedures for avoiding handling damage. None of this should entail any great difficulties.

Table 4-1. Chemical analysis of ingots used for tube no. in ppm.

Element	**Req. acc. to KTS 001, rev 4 (ppm)**	**T25**	**T26**	**T27**	**T30**	**T31**	**T32**	**T33**	**T34**	**T35**	**T36**	**T37**
		Ingot	Ingot	Ingot	Ingot	Ingot	Ingot	Ingot	Ingot	Ingot	Ingot	Ingot
		189-3-1	63-2-1	64-2-1	150-3-1	152-3-1	133-1	82-2	Posiva	64-3-1	65-3-1	351-2-1
		Manuf. 1998										
P	30–70	35–49	44–66	41–66	31.1–35.7	35.7–44.5	40–42	42–60	54–56	41–66	41–66	37–51
Ag	<25	10–13	12.3–12.5	12.3–12.5	11–12	11–12	11	13	13.9–14.3	12.3–12.5	12.3–12.5	10.6–25
As	<5	<2	1.04–1.10	1.04–1.10	1.27–1.35	1.32–1.38	1.36–1.43	1.26–1.32	1.2	1.04–1.10	1.04–1.10	0.092–1.3
Bi	<1	<3.0	0.19–0.21	0.19–0.21	0.4	0.4	0.3	0.3	0.42–0.46	0.19–0.21	0.19–0.21	0.41–0.5
Cd	<1	<2.0	<0.003	<0.003	<0.0	<0.0	<0.05	<0.05	<0.01	<0.003	<0.003	<0.004
Fe	<10	<3.0	1.1–1.3	1.1–1.3	0.4–0.7	0.4–0.7	0.8–0.9	0.4–1.8	0.7–0.9	1.1–1.3	1.1–1.3	0.5–0.8
H	<0.6	–	0.40–0.43	0.40–0.43	0.4–0.52	0.34–0.47	0.1–0.4	0.24–0.52	0.15–0.28	0.4–0.43	0.40–0.43	0.31–0.35
Mg	<1	<0.5			<0.2	<0.2	<0.2	<0.2	<0.1			<0.08
Mn	<0.5	<1	0	0	<0.2	<0.2	<0.2	<0.2	<0.1	0	0	<0.2
Ni	<10	<2	0.4–0.5	0.4–0.5	0.4–0.7	0.3–1.0	0.3–0.4	0.3–0.4	0.8–0.9	0	0.4–0.5	1.5–1.7
O	<5	–	1.8–4.8	1.8–4.8	2.3–5.3	2.5–5.6	3.0–5.7	2.9–5.8	2–2.5	1.8–4.8	1.8–4.8	3.5–5.3
Pb	<5	<7	0.31–0.34	0.31–0.34	0.69–0.81	0.79–0.8	0.65–0.72	0.53–0.65	0.37–0.44	0.31–0.34	0.31–0.34	1–1.7
S	<8	5–8	5.7–6.2	5.7–6.2	6.2–7.0	5.9–6.1	5.8–6.5	5.7–5.9	6.2–6.8	5.7–6.2	5.7–6.2	5.5–5.9
Sn	<2	<1	0.076–0.112	0.076–0.112	0.2–0.22	0.24–0.28	0.33–0.34	0.15–0.16	0.2–0.22	0.076–0.112	0.076–0.112	0.61–0.64
Te	<2	<7	0.25–0.26	0.25–0.26	0.54–0.6	0.46–0.51	0.35–0.42	0.27–0.30	0.39–0.42	0.25–0.26	0.25–0.26	0.51–0.67
Zn	<1	<7.0	0–0.02	0.00–0.02	<0.3	<0.3	<0.3	<0.3	<0.2	0.00–0.02	0–0.02	0.3–0.5

Table 4-2. Mechanical properties and microstructure obtained in extruded tubes.

Tube no.	Yield strength $R_{p0.2}$ (MPA)	Tensile strength R_m (MPa)	Elongation A (%) Req. >40%	Hardness (BHN)	Average grain size (µm) Req. <360 µm
T 25	84	226	62.5	38.6–41.9	32–90
T 26	63	221	63.5	38.6–41.9	32–90
T 27	69	224	62.0	35.7–38.6	32–90
T 31	69	216	63.0	39.0–52.5	64–127

4.1.3 Pierce and draw processing

Computer simulations of pierce and draw processing for the purpose of fabricating copper tubes with integral bottoms have been carried out by Outokumpu Poricopper and Vallourec & Mannesmann Tubes. The simulations have made it possible to study the degree of deformation in the different steps of hot forming. The results have been used to design the tools that are used so that hot working of the bottom is sufficient. Two tubes, T 34 and T 36, have been fabricated with integral bottoms, and another tube is currently in fabrication.

The results for tube T 34 have been compiled in a special report, /13/.

The results of material examination on tube T 34 showed that the grain size at the top of the tube, as well as in the periphery of the bottom, did not exceed 120 µm. The centre portion of the bottom had not been sufficiently worked through. The grain size there varied up to about 1 mm. The whole tube, except the bottom, met the grain size requirement ≤ 360 µm. Following additional computer simulations, further modifications were made to achieve a better machining of the centre of the bottom during the final hot forming steps, see Figures 4-4 and 4-5. This was applied to tube T 36, which was pressed prior to T 35.

The metallographic examination of the bottom of tube T 36 showed that the grain size in the centre of the bottom was 350 µm. At the same time, it was found that the variation in grain size in the bottom was relatively great, see Figure 4-6. No defects were observed in the cross-section through the bottom. The results indicate that pierce and draw processing of tubes with integral bottoms can yield good enough results to be used. Tube T 35 will be another step in this development. But even if pierce and draw processing of tubes with an integral bottom does not turn out to be a practical alternative, it will still be possible to use pierce and draw processing as a method for fabrication of copper tubes open at both ends, along with extrusion and possibly forging.

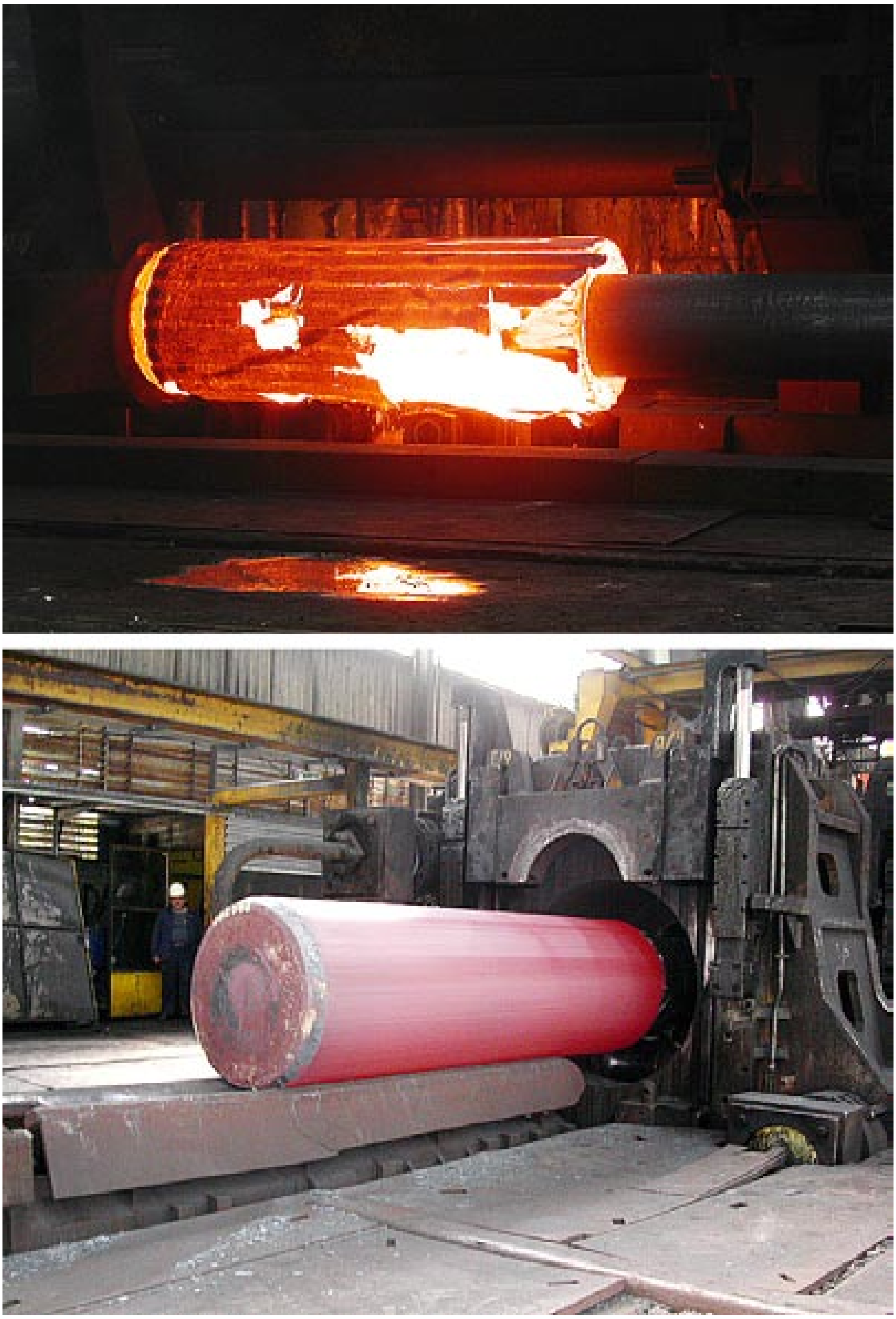


Figure 4-2. *In pierce and draw processing, the copper tube is formed by a series of expansion steps and drawings to the desired size. The top picture shows an expansion and the bottom a drawing that elongates the tube.*

Figure 4-3 A and B. *Tube T 34 with integral bottom after internal and external machining. See also reference /13/.*

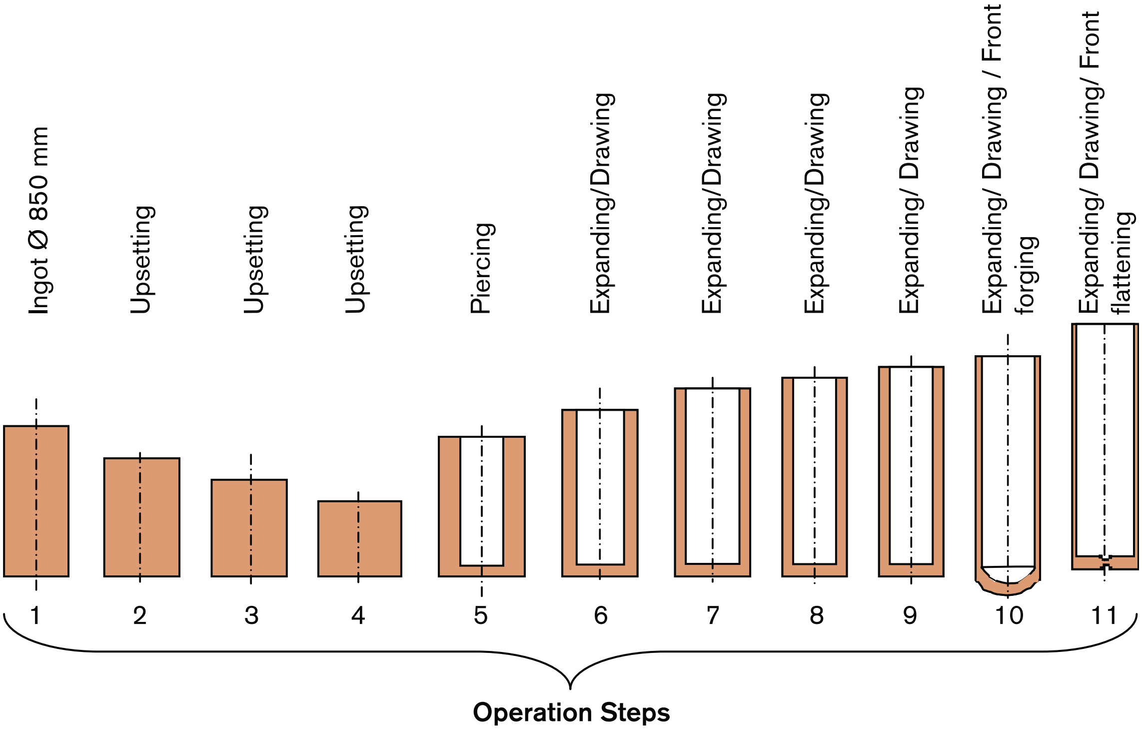


Figure 4-4. *Operation steps for further machining of the integral bottom.*

Figure 4-5. *Tube T 36 after fabrication according to Figure 4-4.*

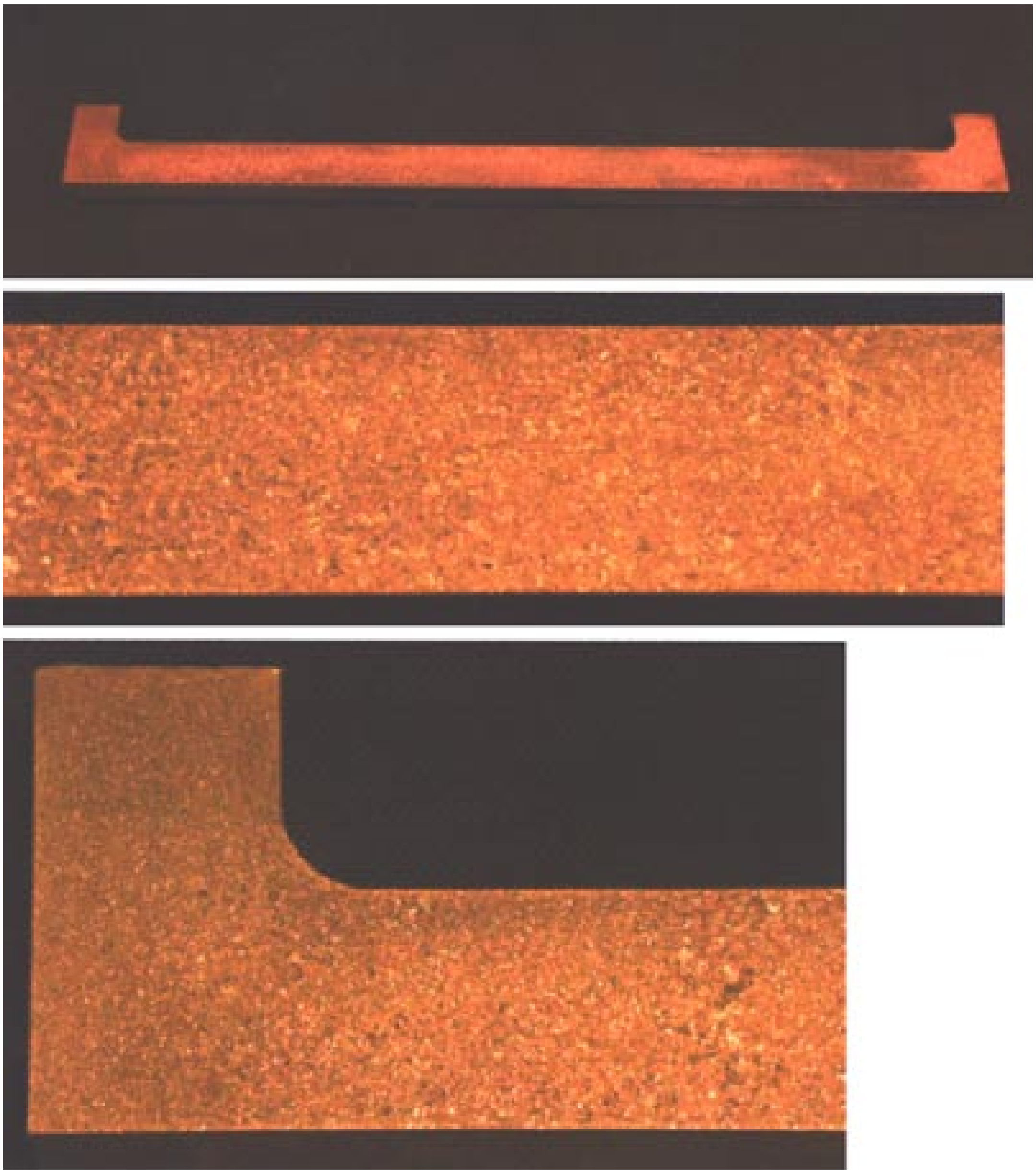
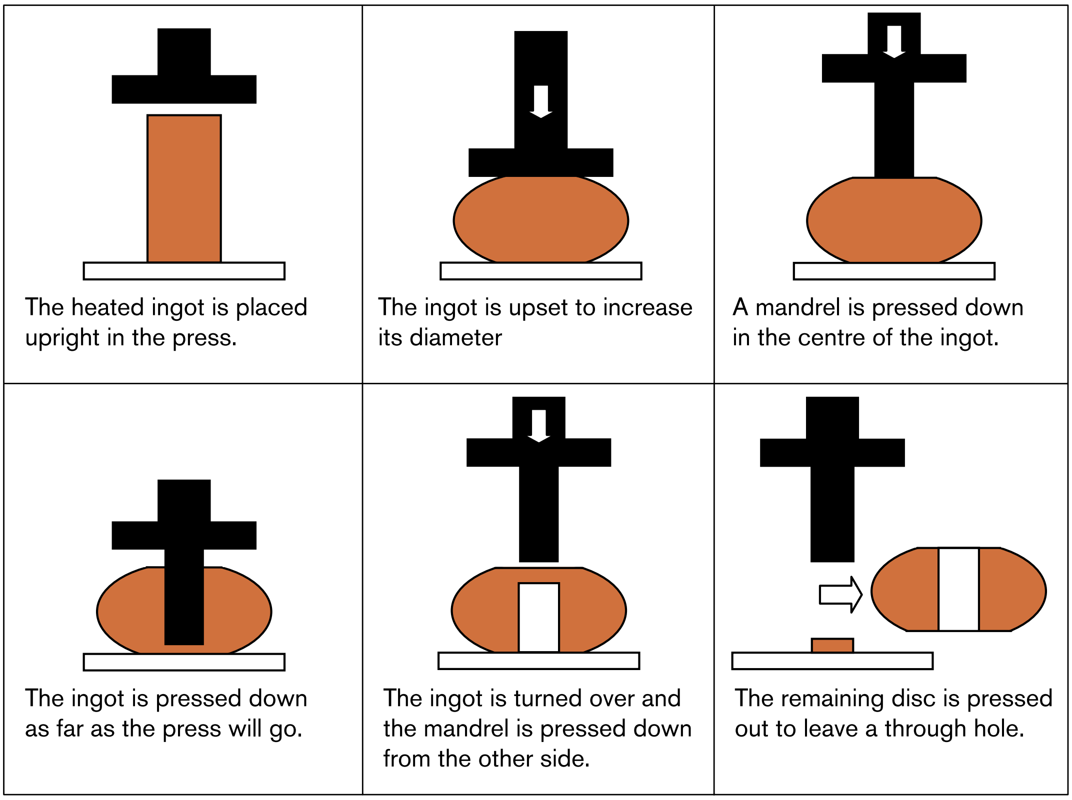


Figure 4-6. The microstructure in a diametrically cut-out cross-section through the bottom of tube T 36.

4.1.4 Forging

A new method for fabricating seamless tubes that has begun to be investigated is forging, and some trial fabrication has taken place. The trial fabrication has been done at Scana Steel Björneborg, which normally makes heavy free-form steel forgings. The entire process is carried out in a press with a press force of 4500 tonnes.

To start with, the ingot is heated and placed upright in the press. The ingot is then compressed to obtain a larger diameter, about 1100 mm. Then a mandrel is pressed down in the centre to create a hole (piercing). See Figure 4-7. The mandrel is pressed down all the way, after which the ingot is turned over. The mandrel is pressed down from the other side of the ingot and a small disc of surplus material is pushed out. The disc is about 60 mm thick and weighs about 80 kg. After this operation, a pierced blank is obtained, which is placed in the furnace for reheating.



The heated ingot is placed upright in the press.

The ingot is upset to increase its diameter

A mandrel is pressed down in the centre of the ingot.

The ingot is pressed down as far as the press will go.

The ingot is turned over and the mandrel is pressed down from the other side.

The remaining disc is pressed out to leave a through hole.

Figure 4-7.

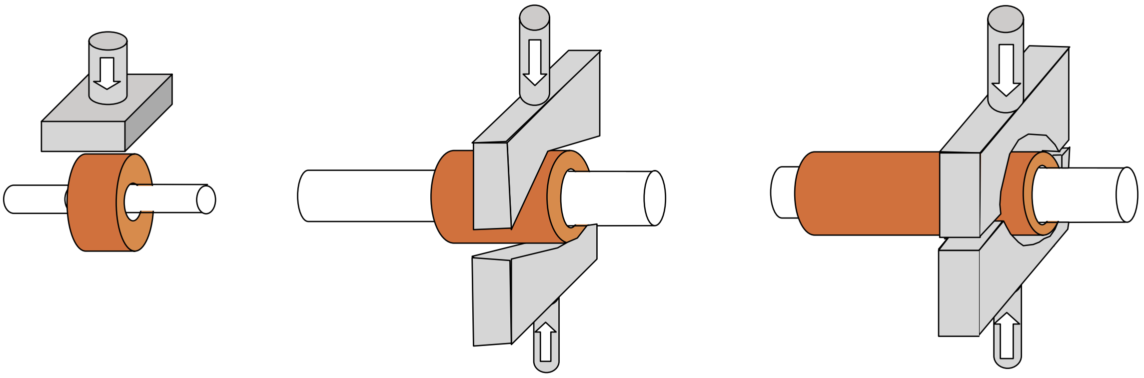
The pierced ingot is threaded over a horizontal mandrel and then subjected to a process called ring forging. In ring forging, a die presses the blank vertically against the mandrel. This is done to increase the inside diameter and get a more even wall thickness. When a sufficient inside diameter has been achieved, the copper ring is threaded onto a thicker mandrel with a diameter equal to the inside diameter of the finished copper cylinder. This mandrel is preheated to about 400°C. The next step is cogging, in which a die is pressed against the mandrel from both directions. The purpose of this is to increase the length of the copper cylinder. To start with a V-shaped die is used until an outside diameter is obtained that fits into the concave die used in the next step. Figure 4-8 A–C illustrates the ring forging and cogging processes. A number of intermediate heatings take place during the ring forging and cogging process.

Figure 4-9 shows the final cogging step in a real setting. In the picture, the tube can be seen mounted on the mandrel to obtain the right inside diameter. The concave dies surrounding the tube can also be seen.

One tube, designated T33, has been fabricated by forging.

There were clear centre cracks at one end of the ingot used to fabricate the tube. The side with centre cracks was positioned facing downward in the piercing operation so that any defects would be pressed out of the material and be left in the disc that is pressed out.

In the first step, an available V-shaped die was used that was not adapted to the tube size used. This die caused some material to flow in the transverse direction instead of in the longitudinal direction as intended. To get a tube with sufficient length and the right diameter, a die that was specially made for the forging of copper tubes was used in a final step. This die was close to the shape of the finished copper cylinder and caused the material to flow better in the longitudinal direction.



A. Ring forging. **B.** Cogging with V-shaped die. **C.** Cogging with concave die.

Figure 4-8 A–C. *Diagram showing forging after piercing of ingot.*

Figure 4-9. *Final cogging operation in the concave die.*

Measurement after forging showed that the inside diameter was slightly too big and that it was bigger at the ends of the tube than in the middle. It was also discovered that there was a relatively great difference in wall thickness around the tube, see Figure 4-10.

The high degree of deformation in the forging process, in combination with the moderate forging temperature, is conducive to a relatively fine-grained microstructure. Grain size specimens were taken at both ends of tube T 33. It was found that the grain size requirements were met with good margin. The grain size was found to be in the range 64–127 µm.

The inside diameter of tube T 33 was machined in a boring mill at KIMAB.

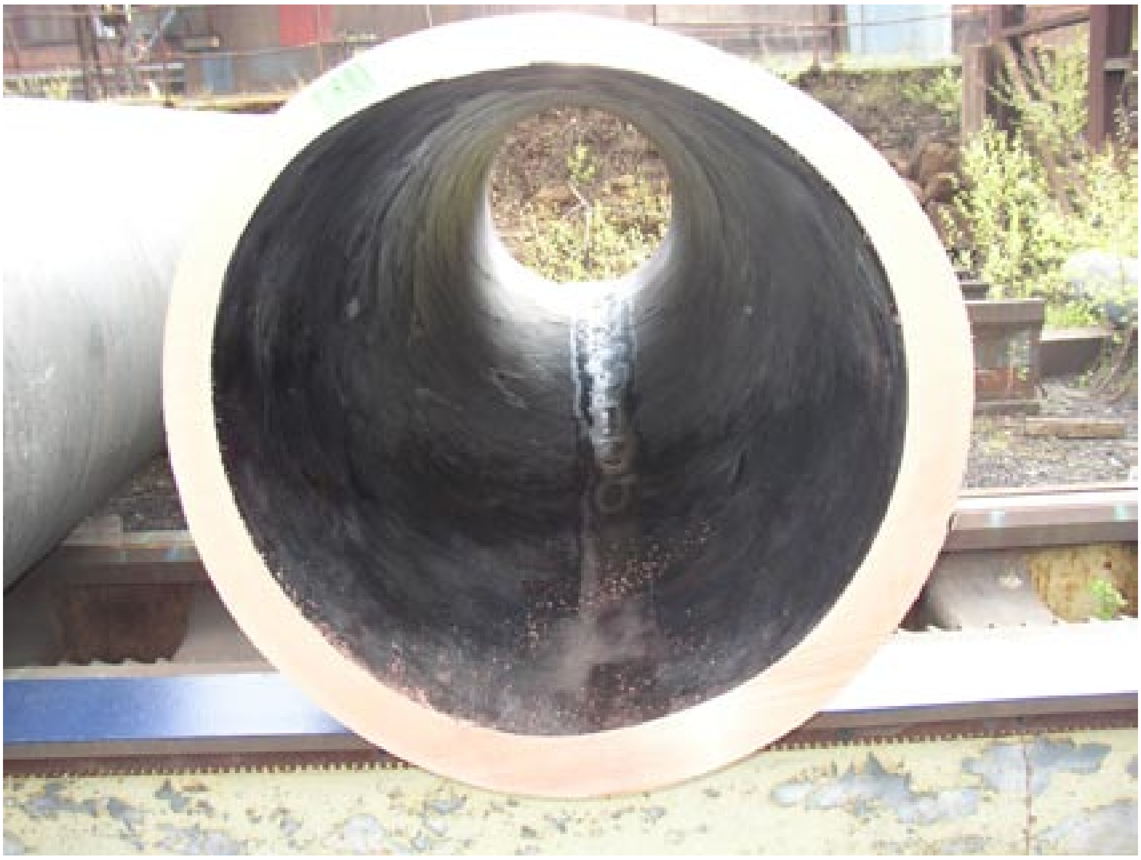


***Figure 4-10.** Picture of sawn tube.*

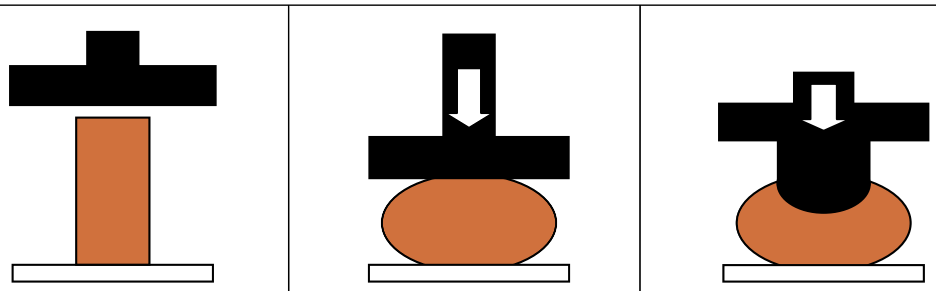
The tube had an ovality at one end that prevented the inside diameter requirement for a tube with a wall thickness of 50 mm, which is 952 mm, from being met. For this reason, the inside diameter was machined to 970 mm, which results in a tube with a wall thickness of 40 mm.

The trials show that forging is a practical alternative for fabrication of seamless copper tubes. Since some material still flows in the transverse direction instead of in the longitudinal direction, further development of the die and the forging technique are required to achieve the right dimensions.

4.2 Fabrication of lids and bottoms of copper

The starting material used for forging of lids and bottoms is a cylindrical ingot with a diameter of 500 mm and a length of 660 mm. To start with, the ingots are heated to about 675°C, after which they are upset in the press to increase their diameter. In the next step, a rounded mandrel is placed in the centre of the ingot and pressed down. The result is a blank with a large pit in the middle. This blank is heated in the furnace and then placed with its flat side facing down in the lower die. The blank is pressed down into the cavity in the lower die by a flat upper die until full press force has been reached. The upper die is then replaced by a peen. The peen is about 400 mm wide and 2 m long and is used to obtain greater force per unit surface area. To start with the peen is pressed into one edge of the lower die, after which the lower die is rotated. When the die has been rotated one revolution, the peen is placed in the centre and rotates until all material has been pressed down into the lower die.

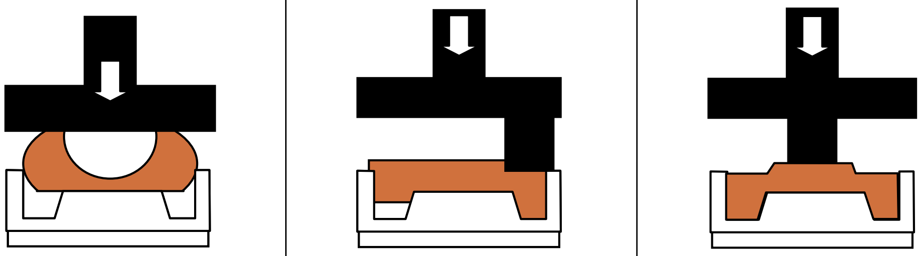
The forging process has been simulated with respect to strains and material flows. This has been done at the Royal Institute of Technology, reference /14/. Since the strain in the material is of great importance for grain size, a conclusion can be drawn as to what the grain size distribution looks like by studying strain during the forging process. The results show that strain is good over almost the entire lid, which in turn suggests that the grain size requirements are met in the entire lid. Figure 4-12 shows a picture from the results of the simulation. The results of the work at the Royal Institute of Technology have been used to optimize the forging dies.



The heated ingot is placed upright in the press.

The ingot is upset to increase its diameter

A rounded mandrel is pressed down into the centre of the ingot.



The blank, with a pit in the centre, is placed with its flat side down in the lower die. The flat upper die is pressed down into the cavity to full press force.

A peen is pressed down on one side, after which the lower die is rotated. The process is repeated until the lower die has rotated one revolution

When the material has been pressed down on the sides, the remaining material in the centre is pressed down.

Figure 4-11. *Schematic diagram of the lid forging process.*

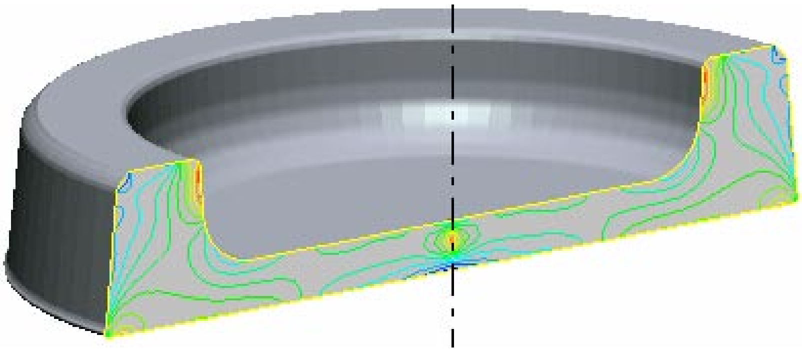


Figure 4-12. *Picture from the simulation of the lid forging process.*

Nineteen lids intended for EBW and 20 lids intended for FSW were fabricated at Scana Steel Björneborg AB. Ingots supplied by Norddeutsche Affinerie AG were used in the fabrication. The ingots are continuously cast and have a weight of about 1100 kg. The chemical composition of the ingots is shown in Table 4-3.

The difference between the FSW and EBW lids is that the FSW lids have a higher flange so that there will be room to park the hole during welding. Due to the higher flange, a deeper cavity is needed, which in turn makes it more difficult to get good mould filling. In the forging of the first FSW lids, it was not possible to finish-machine the whole surface due to the fact that mould filling was not good enough in the upper corners. The fabrication method for lids has, however, been refined and mould filling is now good.

Table 4-3. Chemical analysis of ingots for copper lids.

Element	Req. acc. to KTS001 (ppm)	TX50–TX68 (ppm)	TX69–TX73 (ppm)	TX74–TX88 (ppm)
P	30–70	40–50	40–45	40–45
O	<5	3	1–3	2
S	<8	6–7	7	6–7
Ag	<25	12	12	12
As	<5	1	1	1
Fe	<10	2	2	2
Sb	<4	1–2	2	1–2
Te	<2	<1	<1	<1
Pb	<5	<1	<1	<1
Bi	<1	<1	<1	<1
Cd	<1	<1	<1	<1
Mn	<0.5	<0.5	<0.5	<0.5
Ni	<10	2	2	2
Sn	<2	<0.5	<0.5	<0.5
Zn	<1	<1	<1	<1

Figure 4-13 A and B. *Photos of a finish-forged lid blank (A) and a lid no. TX 76, after machining (B).*

An EBW lid and an FSW lid were sawn apart and the grain size was examined over the cross-section. The grain size examination was performed by Bodycote CMK. The results show that the grain size requirement is met with good margin. The grain size in the FSW lids varies between 90 and 127 µm, while the grain size in the EBW lids is slightly larger, see Table 4-4. Figure 4-14 shows the locations of the extracted microspecimens.

Table 4-4. Measured grain size in forged lids.

Specimen no. (For location see Figure 4-14)	Grain size TX84 ASTM	µm	TX52 ASTM	µm
1	4	90		
2	4	90	3–4	127–90
3	4	90	5	64
4	4–5	90–64	1–2	254–180
5	5	64	3	127
6	4	90	3–4	127–90
7	4	90	4	90
8	4	90	4	90
9	4	90	4	90
10	4	90	3	127
11	3	127	3	127
12	3	127	3–4	127–90
13	4	90	3–4	127–90
14	4	90	4	90
15	3–4	127–90	3	127
16			1–2	254–180

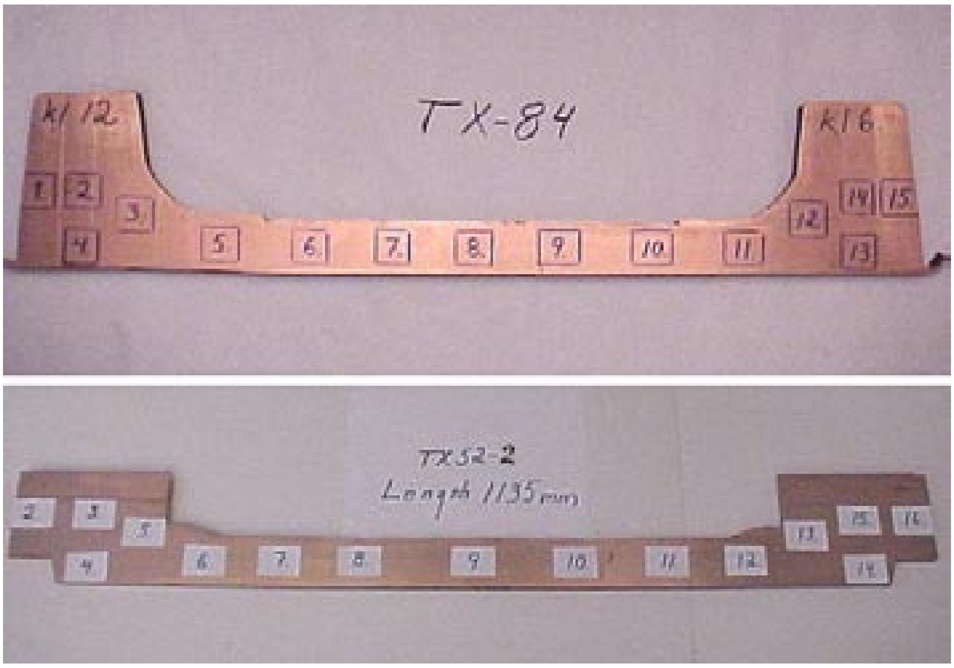


Figure 4-14. Where the grain size specimens were taken out.

Tensile testing was also performed on 3 lids in order to ensure that the requirements for elongation values given in KTS 002, Appendix 3, are met. The tensile tests were performed by Bodycote CMK. Table 4-5 shows the elongation values for the three lids, which meet the requirements.

Forging of blanks for lids and bottoms has been developed into a well-functioning method. In the continued work, the technology for nondestructive testing will be developed, see Chapter 6.

Table 4-5. Results of tensile testing of test bars made from forged lids.

Lid blank no.	$R_{p0.2}$ MPa	R_m MPa	A_5 % (req. >40%)
TX79	81	214	50
TX82	96	216	54
TX88	89	217	56

5 Development of FSW

The preceding status report, /3/, contained a relatively detailed account of the development project Friction Stir Welding (FSW) of copper in cooperation with TWI. This basic research project was conducted between 1997 and 2002. A summarizing report on the project work at TWI has been compiled /15/. The work resulted in three patents /16–18/.

Continued development after this is being conducted at SKB's Canister Laboratory in Oskarshamn with the full-scale machine installed there.

6 Nondestructive testing (NDT)

6.1 Overview

Nondestructive testing (NDT) is often used to ensure that a component meets certain acceptance requirements, especially when the component has a critical function. NDT can also be used to make sure that a certain fabrication method produces the desired results. When a component is tested after fabrication, this can provide an indication that something has gone wrong during fabrication or that certain fabrication parameters need to be changed. These are just some of the applications for which different NDT methods can be used.

For SKB, the use of different NDT methods largely has to do with verifying that fabrication processes work like they should and that the integrity of the canister is ensured. What has previously been studied within fabrication technology and NDT has been to see whether the various fabricators have the means to carry out the desired testing. Efforts have therefore been focused on finding out what methods are used and evaluating them. Some trials have been conducted with methods that are relatively new and specially designed for the different components. Development work is also being carried out on various methods to see if it is possible to modify them so that they are better adapted to the canister.

This study has focused on some of the canister's components. The reason has been that these components are considered to be more or less suitable for SKB's purposes. The components are specially made and have not previously been serial-produced by any suppliers.

The components that have been studied from an NDT perspective are:

- the copper cylinder,
- the copper lid and bottom,
- the insert.

There is not much NDT experience from copper products of this size. The nodular iron insert also entails a complexity due to its special design. A progressive accumulation of experience in terms of both fabrication parameters and testing results is important in the continued work. The fabrication processes and NDT methods must be developed to a reliability that will guarantee adequate safety for the final repository.

Certain components, such as steel lids and bolts, can be purchased against certificates. Furthermore, these are more or less standard products and are therefore not considered so interesting in the perspective of the above discussion.

6.2 Nondestructive testing of cast inserts

6.2.1 Testing conditions, insert

The insert consists of two different parts: the channel tubes and the cast part. This affects the testing somewhat, at the same time as the geometry of the insert makes it difficult to carry out complete testing with only one testing method. The areas between the channel tubes are difficult to test with any NDT method.

This part of the insert presents a number of problems due to its geometry. The outer areas can be tested by means of e.g. ultrasonic testing. However, the same method cannot be used for testing of the areas between the channels. The illustration below shows a cross-section through the canister.

A number of difficulties for different NDT methods are apparent from the drawing in Figure 6-1:

1. It is difficult or impossible to obtain a reflection from an underlying surface (bottom echo) in certain positions (ultrasonic testing).
2. There is little or no bond between the channel tubes and the nodular iron, making testing from inside the channel tubes impossible (ultrasonic testing).
3. The area between the channels is difficult to examine, since there are many obstructions, such as channel tubes (ultrasonic testing).
4. The thickness of the casting makes it difficult to penetrate by means of other methods (radiographic testing).
5. The size of the object can entail certain problems (about Ø900–1000 mm).
6. The interfaces between nodular iron and steel plate are not perfect, but relatively irregular.

Depending on how certain defects are oriented in the nodular iron, it may be difficult to detect them. In some cases, large porosities, for example, have such a geometry that they completely reflect away the ultrasound. In such a case it is difficult or impossible to detect these defects if there is no bottom echo to analyze. Normally, such a defect can be indicated by a bottom echo reduction. In these cases, other methods should be evaluated (e.g. Phased Array and TOFD) for their ability to detect these types of flaws.

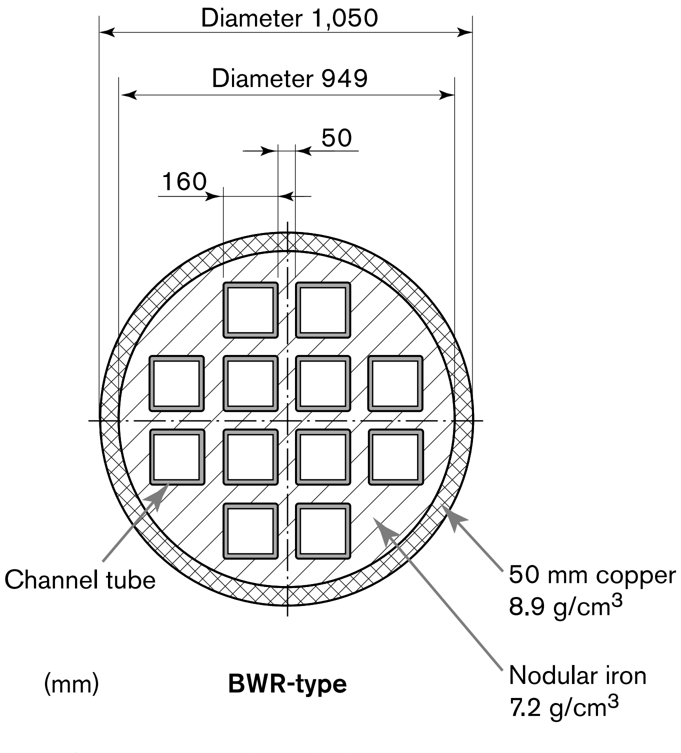


Figure 6-1. *Drawing of cross-section through the canister.*

The cylindrical shape is a relatively favourable geometric factor. This shape provides ample opportunity for utilizing rotational symmetry in an automated testing procedure.

Another thing that should be mentioned is that the channel tubes are welded together during fabrication with spacer plates. Since the bond between steel plate and nodular iron is limited, this will also limit testability.

No reference body is available for the insert. Such a body will be adapted to the acceptance criteria that are stipulated, as well as to the relevant method (through-transmission, pulse-echo).

6.2.2 Conducted testing, insert

A number of inserts have been tested, though not completely. In this case, several different methods have been used to test different parts of the insert. Figure 6-2 below shows a possible subdivision of the testing.

Ultrasonic testing has been used exclusively. Based on the above picture, it can be noted that the surface areas were tested with a double crystal probe (2 MHz), while areas with thicker metal were tested with a single crystal probe (1 MHz). The areas between the channels were tested by means of an experimental method using through transmission of ultrasound. Thus, the ultrasound will be transmitted through the channel and registered on the opposite side in the event there are no defects. The through-transmission technique is illustrated below (Figure 6-3).

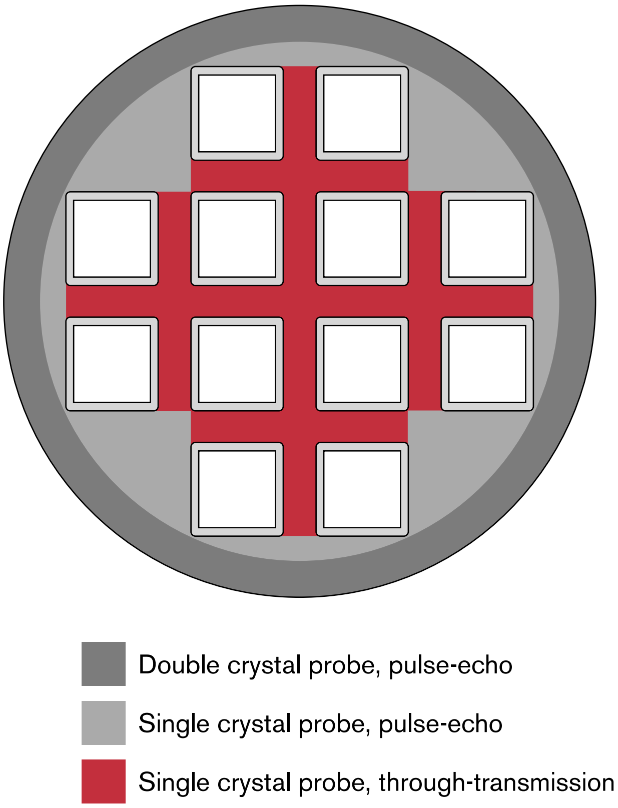


Figure 6-2. *Subdivision of the insert for different kinds of testing.*

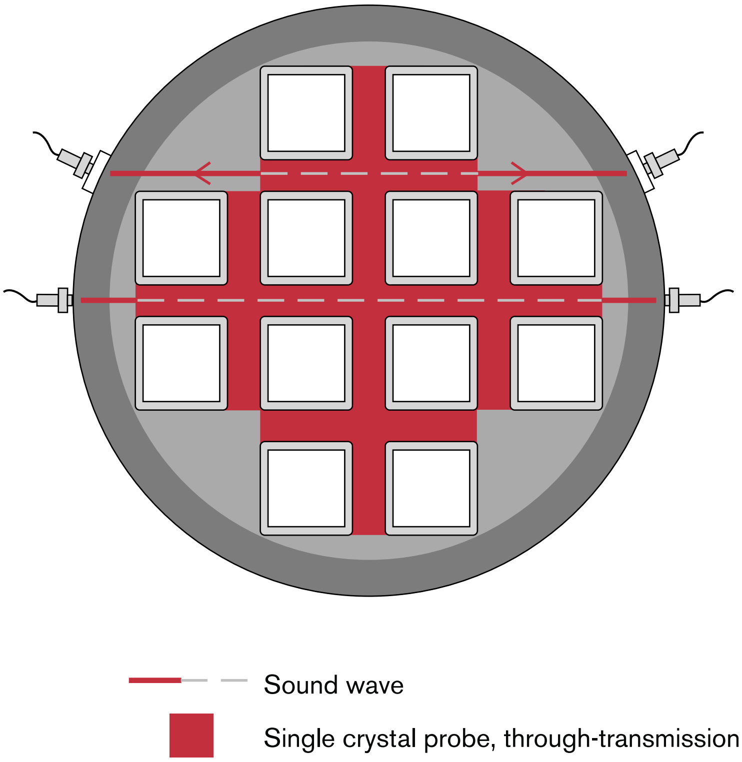


Figure 6-3. *Through-transmission testing of the insert.*

The preliminary results have shown that this method is able to indicate relatively small defects. However, detectability has not been tested to see how well the method works. This should be done for most of the methods mentioned in this report.

In order to test the area between the outer channels, wedges have been fabricated to make sure the ultrasound is transmitted to the object and can ultimately be registered by the probe. The results of these tests reveal several things:

1. The method can detect small pore clusters as well as larger defects.
2. The method also indicates the spacer plates that are used in the assembly of the channel tubes (can be seen to some extent as a preliminary and rough detectability of about 60 mm).
3. The method can be complemented by pulse-echo if an indication needs to be studied further.
4. The method also appears to have a potential to indicate significant material changes in the insert.
5. The method should lend itself relatively well to mechanization.

If testing is conducted through all channel positions, the results can be compiled and provide a better picture of where indications may be present in the cross-section being tested (see Figure 6-4 below). This can then be utilized in combination with complementary testing by pulse-echo. From the different individual through-transmission tests, it is possible to obtain a picture of the entire cross-section through a given position on the insert. At the same time, it is possible to visualize fairly well the size of an indication.

An example of a defect that could be detected by the through-transmission method is shown in the figure below. The size of the defect is about 50×30 mm.

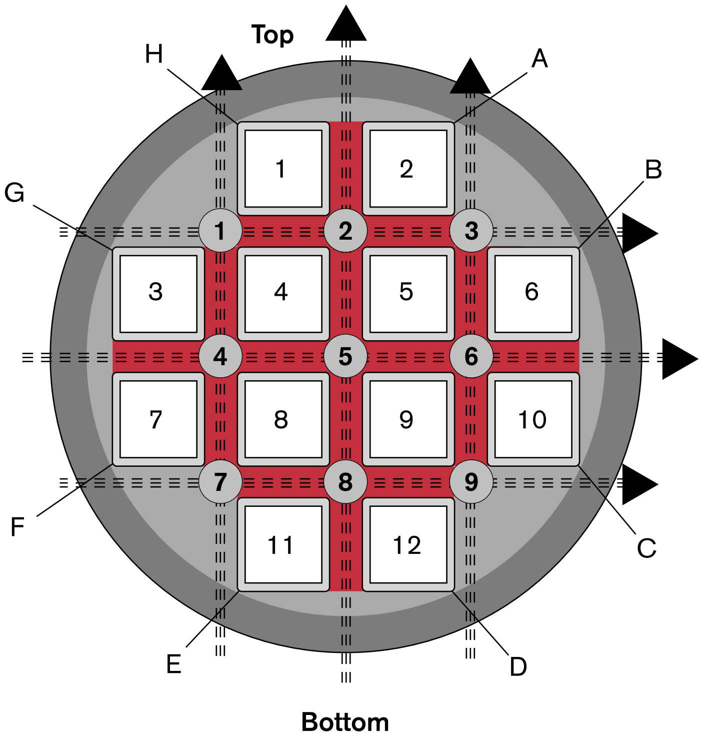


Figure 6-4. *Interlinked tests.*

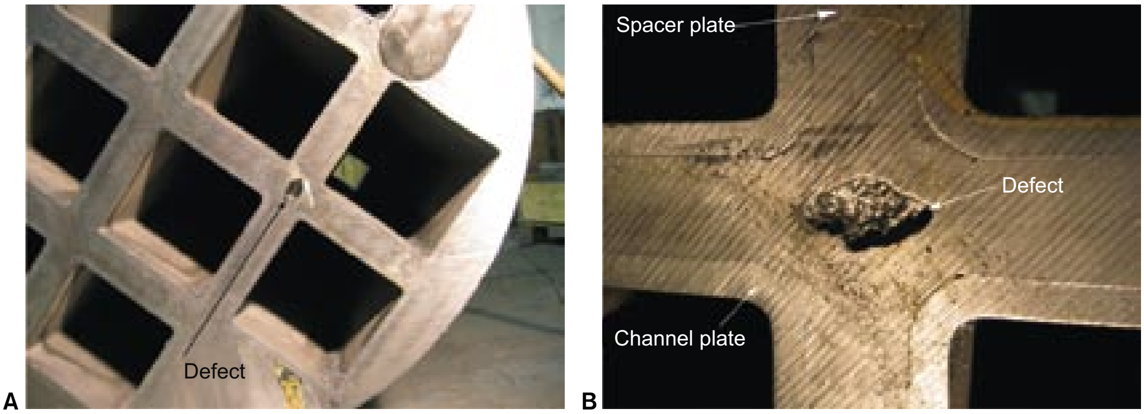


Figure 6-5. *Examples of detected defects.*

6.2.3 Potential and limitations of current technology, insert

The ultrasonic method (pulse-echo) of examining the outer areas may entail some problems, since it is not possible in all positions to analyze changes in the bottom echo. Further studies should therefore be focused on determining what the limitations are and what additional measures may be needed to rectify this.

Pulse-echo has been used with good results to determine the position of the channel tubes in the insert after casting. It has further been possible to roughly estimate the bonding that occurs between channel tube and nodular iron.

Spacer plates are used between the channel tubes during fabrication to prevent them from moving during casting. The spacer plates give rise to interfaces in the insert which make it difficult to test the sections where they are located. The position of the plates has turned out to be relatively simple to determine in testing with both through-transmission and pulse-echo.

These methods are very amenable to mechanization and automation, since what is mainly needed is different rigging systems. The initial studies of detection potential and the trials have shown that the methods have good potential in this respect. Some reservation for the test with pulse-echo should be noted, as discussed above.

6.3 Nondestructive testing of copper components

Two different copper components are used in the planned canister design: lid/bottom and cylinder. Certain initial trials have been conducted for lid and bottom, although no standardized or method-specific testing. Some attempts have been made to measure sound attenuation in copper by means of ultrasound. The attempts showed that ultrasonic determination of material parameters shows some potential.

More tests have been performed for the cylinder. The cylinder fabricators have conducted their own tests and reported the results to SKB. The technique for testing the component has varied widely between the different fabricators. The following sections will deal with the testing conditions, conducted testing, and potential and limitations of current technologies.

6.3.1 Testing conditions, copper components

The geometries of these components cannot be said to be restrictive or inhibitive for testing. Ultrasound is normally used to detect volumetric defects in similar steel components. Another testing method can be used as a complement if the surface is considered particularly important based on the acceptance criteria. Based on the given geometries, there are good chances of being able to ensure detection of certain defects by using different NDT methods. For information on the geometries in question, see SKB's engineering drawings.

Copper components of the wall thickness in question here are relatively unknown from an NDT perspective, and this needs to be investigated and characterized. Furthermore, existing detection requirements will require some characterization of defects. Characterization of certain types of defects may require modification of the equipment. In some cases the equipment may have to be modified so that it is given new functions.

In view of what has been said above, it will be interesting to obtain information on what types of defects can be expected to occur with the different fabrication methods. This information, and the detection requirements that exist to meet future acceptance criteria, will then provide information on what type and scope of testing is necessary. At the present time, the methods that have been used have been chosen based on existing knowledge concerning other components from the fabricators as well as current testing activities.

What is technically interesting is the characterization of possible defects. In some cases, detecting defects does not require any major technical modifications or advanced systems. But it is much more difficult if a defect is detected and must be characterized and size-evaluated. There are no detection requirements or acceptance criteria at present, but work is under way to derive them.

Different types of reference defects will be used in the first reference bodies:

1. Flat-bottom holes, FBHs.
2. Side-drilled holes, SDHs.
3. Grooves.

The size of these defects will ultimately be determined by the acceptance criteria. The reference body that is planned to be fabricated for testing of the copper cylinder will have the following set of reference defects (at the present time):

1. FBHs; Ø2, Ø4, Ø8 and Ø12 mm at different depths in the material.
2. SDHs; Ø4 and Ø8 mm at different depths in the material.
3. Grooves with depths of 0.5, 1, 1.5 and 2.5 mm from both the outside and the inside.

The same types of defects will be present in the reference body to be used for testing of lids and bottoms. However, the grooves will not be usable for the preliminary testing method planned to be used for these components.

6.3.2 Conducted testing, copper components

No testing method has been used for lids and bottoms. The testing that has been conducted has been limited and focused on special cases. Measurements of sound attenuation have been performed and the results compared with grain size. These measurements have been performed on lids and have shown that sound attenuation can provide a satisfactory indication of grain size.

The copper cylinders have been tested by the respective fabricators. At present, these are the fabricators who have some kind of mechanized or automated testing methodology:

1. Wyman Gordon Ltd (W-G).
2. Vallourec & Mannesmann Tubes (V&M).

The methods employed by these fabricators are similar. Ultrasonic testing is used and performed in different directions (radial and axial). Since W-G does not have facilities for machining the extruded cylinders, it is not possible to test them in the axial direction. In other words, the extruded cylinders from W-G have only been tested in the radial direction. It should also be mentioned that the testing is conducted using a gap method, with a water gap as the coupling medium between ultrasound probe and test object. This applies to testing at W-G and V&M. The results of the testings exhibit no indications.

The testing conducted at V&M is more thorough. In this case, testing is performed on a machined surface. It is then possible to test the cylinder with different directions of the ultrasound. The advantage of testing in different directions is that more types of defects can be indicated. For more detailed information on current testing activities, see /19/.

6.3.3 Potential and limitations of current technology, copper components

If testing is only performed in the radial direction, numerous types of defects will not be detectable. For this reason, testing in one direction only is clearly inadequate. The testing at W-G can therefore be regarded as inadequate if complementary testing is not performed. At V&M, testing is performed in different directions. This makes it possible to detect more types of defects. Furthermore, a reference body is used at V&M. The reference defects

(Ø4 mm FBHs and 0.6-1.2 mm deep grooves) in it can be indicated by existing technology. However, this was done in a static state and not when the reference ring was rotating.

The figure below shows the setup that was used for testing at V&M.

The different ultrasonic probe assemblies used are shown in the above figure. These assemblies used ultrasound in different directions. Part 1 scanned with ultrasound in the radial direction (normal to the surface) and with 5 MHz as the probe frequency. Parts 2 and 3 scanned axially (45° in steel) in different directions with a probe frequency of 1 MHz. The axial (transverse and longitudinal) scan was done in 4 different directions.

With the testing method used at V&M, it is possible to detect defects that extend in most directions. The reference ring also provides a rough indication of the method's detectability (0.6 mm deep grooves Ø4 mm FBHs).

The limitation of this method, however, is that it is only possible to detect defects. It is not possible to size-evaluate and characterize the indications. Discussions have also been held with V&M on the possibility of implementing a Time Of Flight Diffraction (TOFD) method. However, this would entail large investments by the fabricator.

Some method development is required in order to be able to detect defects in different directions and at the same time be able to size-evaluate and characterize them. Phased Array and TOFD are examples of methods that have this capability. Since Phased Array is used at the Canister Laboratory, studies have been initiated to see whether this method has future potential for the copper cylinder as well.

Figure 6-6. *Test setup at Vallourec & Mannesmann Tubes.*

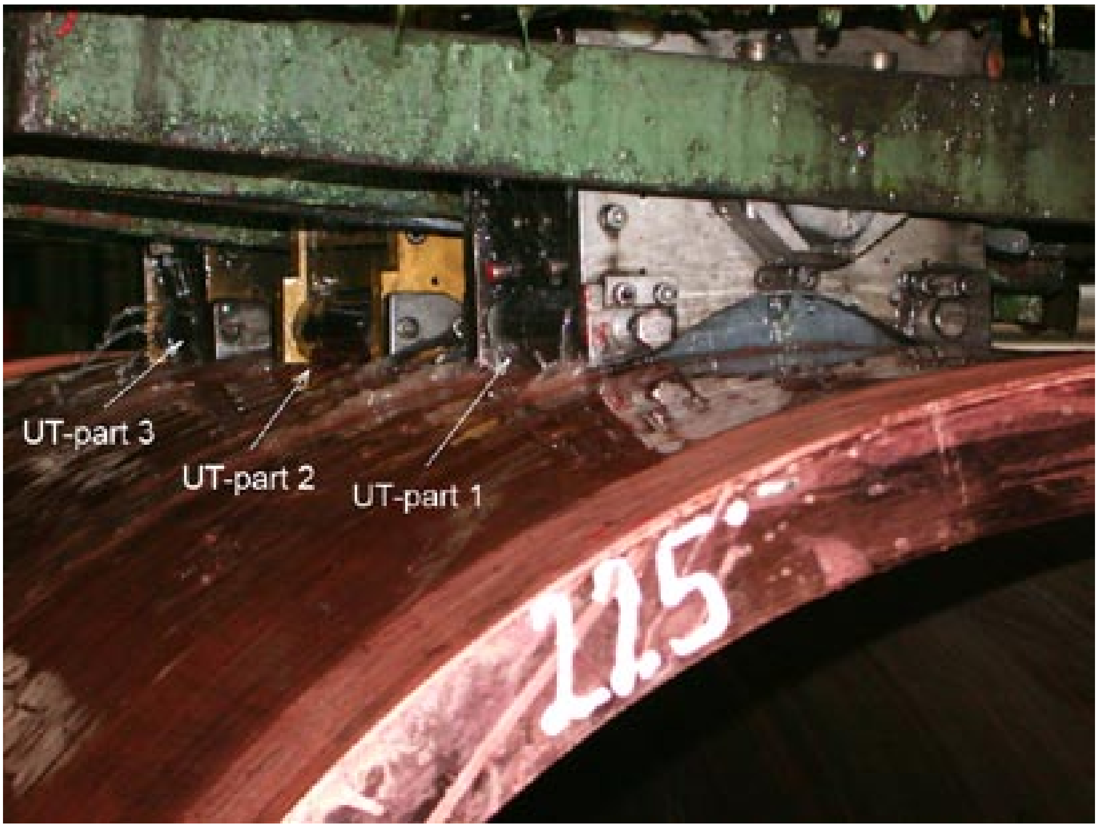


Figure 6-7. *Ultrasound in different directions.*

At present there is no method that is automated and tests integral bottoms. This testing is performed manually with a normal probe. Experience from the testing that has been done is that defects are mostly detected in the bottom. The same reference body was used in both the manual and the automated testing, and it shows that there are indications exceeding Ø4 mm FBH. It should also be pointed out that manual testing with a normal probe entails limitations in detectability.

6.4 Future lines of investigation

Experience accumulation and method development will take place during the period 2004–2005. This work includes carrying out testing on more objects and conducting planned detection tests on the different components.

Preliminary NDT procedures are planned to be established during 2005. As a part of this work, suitable reference bodies will be developed.

Continued experience accumulation and evaluation of reliability will take place during the period 2006–2007. This work will be pursued in close cooperation with the Canister Laboratory.

Further investigations will be conducted of the possibilities of determining material parameters in both copper and nodular iron by means of ultrasound. In copper the grain size is of interest, and in nodular iron the nodularity of the graphite.

Several different defect types are emerging within the project "Probabilistic analysis of canister strength". These will be studied more thoroughly by NDT and they will be catalogued. Further studies of possible defect types are planned along with continued information exchange with the Canister Laboratory.

6.5 Laser equipment for dimension measurement of copper tubes

In order to improve the fabrication of copper tubes and be able to control the process better, a measurement apparatus has been developed in cooperation with the Royal Institute of Technology. The apparatus is based on laser technology and is capable of measuring roundness, straightness and the inside diameter of the tubes.

The principle behind the measurement apparatus is popularly known as "laser triangulation". A laser beam illuminates a point on the surface to be measured. This point scatters the light due to the roughness of the surface. The position of the shining point is recorded by a "camera system" located at a well-defined distance next to the light source. A good image can be obtained within the camera's focal range, where each point in the camera's image plane corresponds to a given distance between the laser light source and the surface to be measured. In simplified terms, it can be said that the distance to the surface is translated into a lateral shift in the image plane (see figure below).

By moving the laser measuring head (containing laser and "camera") sideways, it is possible to register height changes in the surface. In our case, the measuring head is rotated around a centre axis in the cylindrical copper canister to be measured, yielding a radius measurement as a function of the angle of rotation.

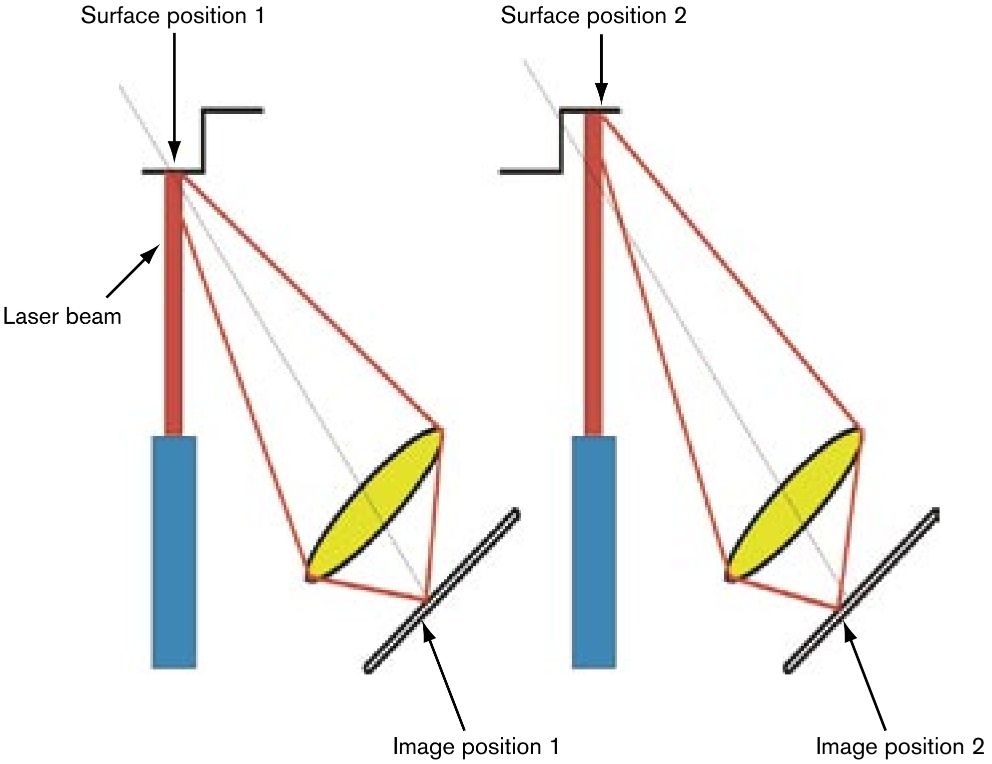


__Figure 6-8.__ Principle for laser measurement of a copper tube.

The measurement apparatus is mounted on a round bar which is fixed in the centre of the tube by a support on either side, see Figure 6-9.

The laser head is then allowed to travel on the bar and record the radius at different lengths and at different angles. The results are then processed by a computer program and out-of-roundness and out-of-straightness can be charted. The measurements that have been done show that the method works very well and has a repeatability of approximately ±0.4 mm. Figure 6-10 shows examples of values measured on a copper tube.

Figure 6-9. *Measurement of the internal radius of a copper tube.*

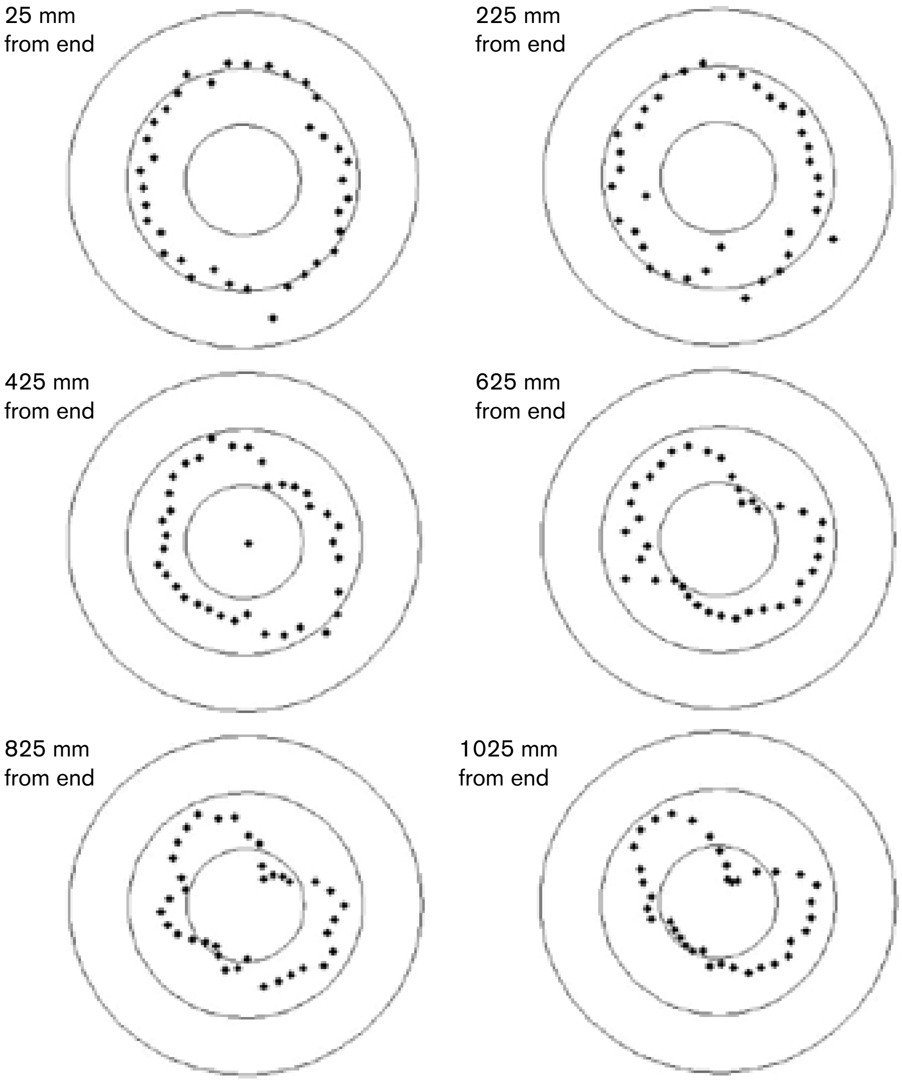


Figure 6-10. *Examples of values obtained from the internal measurement of a copper tube. The figures show the deviation from the nominal radius (middle circle). The distance between the circles is 0.75 mm, corresponding to the drawing tolerance of 1.5 mm on the radius.*

7 Quality control

The work of development of the quality system for canister fabrication described in reference /3/ has continued. This is a part of SKB's overall quality system and is certified to ISO 9001 and 14001. The controlling documents for canister fabrication are compiled in "Manual – Canister Fabrication" and in a separate binder: "Drawings, specifications and procedures." In addition to an overview of fabrication drawings, this binder contains technical specifications, procedure descriptions and forms for various purposes. The contents of "Manual – Canister fabrication" are shown in Appendix 8. Appendix 9 contains a list of procedures. Procedures and technical specifications are written in English so that can be used by foreign suppliers.

A number of technical specifications have been referred to previously in this report. The technical specifications contain material requirements as well as requirements on testing, machining, documentation and certain delivery conditions. A list of all technical specifications is provided as Appendix 1. Appendices 2–7 to this report contain the following technical specifications:

Appendix no	Technical specification	Title
2	KTS 001	Copper Ingots and Billets for Canister Components
3	KTS 002	Copper Components for Canisters
4	KTS 011	Nodular Cast Iron EN 1563 Insert
5	KTS 012	Steel Lid for Canister Inserts
6	KTS 021	Steel Section Cassette
7	KTS 022	Profiles for Steel Section Cassette

The quality system for canister fabrication is being developed continuously. Lessons are learned from trial fabrication and quality audits of suppliers and the results of development projects at institutes and universities, and necessary changes are made in new editions of the controlling documents.

An important ongoing project is establishing acceptance criteria for all parts of the canister, including any welds. These criteria must be specified for both superficial defects and discontinuities inside the material. Established acceptance criteria must be able to be verified by NDT. An account of the ongoing work regarding suitable equipment and methodology has been given in Chapter 6 of this report.

Relevant fabrication processes and inspection and testing procedures must be qualified. This work has begun and will be pursued over the next few years.

8 Future serial production. Canister factory

According to SKB’s plans, the future serial production of canisters for the encapsulation plant will take place in a special canister factory built and equipped for this purpose. Both references /2/ and /3/ made reference to preliminary analyses of such a plant. No further investigation has been done after reference /3/. The factory is planned for mechanized finish machining of all canister components, possible welding of bottoms on the copper tubes, nondestructive testing and assembly into complete empty canisters for delivery to the encapsulation plant. Blanks for all components will be delivered to the factory by various subcontractors.

In a new future investigation, experience from trial fabrication of all canister parts will be taken into account. The work of researching and establishing acceptance criteria and testing methods will make it possible to specify modified equipment for NDT and other quality inspection more precisely. A more thorough evaluation of suitable machinery and testing equipment will be made in cooperation with potential suppliers. This will provide opportunities for a more precise analysis of the factory’s layout and investment costs.

If the development of FSW shows that the technology is to be used in canister fabrication, the consequences of this will be investigated and weighed into the factory layout and investment costs. In order to get a complete picture of potential uncertainties, a risk analysis will be conducted of operations in the planned canister factory.

One step in the ongoing work of development of the quality system for canister fabrication is finding the necessary network of suitable subcontractors and creating a long-term and businesslike relationship with them. In conjunction with ongoing trial fabrication, continuous assessment of suppliers will take place through regular quality audits and analysis of pricing, delivery reliability and probable future development. This work is important for ensuring deliveries of starting material material and services to the future canister factory.

A study of the environmental impact of canister fabrication has been initiated.

9 Continued work

The work of development of fabrication technology and quality assurance will continue over the next few years. SKI has stated that prior to the time of a permit application, SKB must have demonstrated that methods for fabrication and inspection are available and are suitable for serial production. This means that a sufficiently large number of canisters must have been fabricated and inspected and shown to satisfy stipulated requirements.

The account of work done provided in this report shows that fabrication methods are available for all canister parts. The results to date also show that it is highly probable that these methods can be developed and gain acceptance for use in serial production. In most sections of the report, various concrete issues have been presented that require further development work in the form of research and practical tests. Furthermore, a number of ongoing research and development projects at institutes and universities are mentioned in the report. The following bulleted list has been compiled to provide an overview of important work planned during the next few years.

Cast inserts with steel lids

- The development project on probabilistic analysis will be concluded during 2004. The results will serve as a basis for the establishment of acceptance criteria and precise material requirements that ensure that the inserts will meet the design requirements.
- Additional inserts for BWR assemblies will be cast and evaluated against established requirements. Certain inserts will be cut up for particularly thorough material studies. In conjunction with continued trial fabrication, technical specifications and fabrication drawings for channel tubes and the welded cassette will be further developed.
- Only one insert for PWR assemblies has been fabricated so far. Several inserts for PWR assemblies will be fabricated and evaluated in a similar manner to inserts for BWR assemblies.
- SKB will support and participate in a doctoral thesis project entitled "Improved graphite microstructure in thick-walled nodular cast iron" at the School of Engineering in Jönköping and the Swedish Foundry Association.
- The technology and procedures for casting, rough machining, inspection and delivery of inserts will be further developed in cooperation with the foundries.
- Methodology and equipment for nondestructive testing by means of ultrasound as an inspection method will be developed. Besides detection of discontinuities in the casting such as porosities and slag, the possibilities of using ultrasound to inspect the nodularity of the graphite in the nodular iron will be studied.
- Steel lids for inserts will be fabricated to cover the need for fabrication of complete canisters. The objective of the continued work is to further refine the design with associated material specifications and quality assurance criteria.

Copper tubes with lids and bottoms

- Seamless copper tubes and blanks for lids and bottoms will continue to be fabricated in order to verify and further optimize tools, process parameters, inspection methods and technical specifications.

- Seamless copper tubes will be fabricated by means of the three methods: extrusion, pierce and draw processing and forging.
- The development work on fabrication of copper tubes with integral bottoms by pierce and draw processing will continue.
- Fabrication will be carried out primarily for a wall thickness of 50 mm, but also on a limited scope for 40 mm in order to gain experience and gather data as a basis for a possible later decision on a change.
- In the continued work on tube fabrication, the advantages and disadvantages of the different methods will be compared. It is likely that more than one of these methods will be able to be used for future serial production.
- Development of laser technology for dimension measurement of copper tubes will continue.
- Methodology and equipment for nondestructive testing by means of ultrasound as an inspection method will be developed. Besides detection of discontinuities in the casting, the possibilities of using ultrasound to determine the grain size in the fabricated copper components will be examined.

Nondestructive testing (NDT)

- Experience accumulation and method development will take place during the period 2004–2005.
- Preliminary NDT procedures will be established during 2005, according to plans. As a part of this work, suitable reference bodies will be developed.
- In parallel with method development, the possibilities of automating the testing will also be studied. The size of the components makes automated testing preferable. The detection capabilities of the methods should also be studied in an automated case. Furthermore, a large amount of data on the tests should be collected for statistical calculations.
- Continued experience accumulation and evaluation of reliability is planned during the period 2006–2007. This work will be pursued in close cooperation with the Canister Laboratory.
- Within a portion of the project, attempts will be made to characterize different material parameters using NDT methods. The primary purpose is to make it possible to determine the nodularity of the nodular iron and the grain size of the copper.
- The presence of different types of defects in nodular iron is being studied in the project concerned with probabilistic analysis of insert strength. They will be catalogued from an NDT perspective.
- Further studies are planned of possible defect types that can arise during the different fabrication processes in both copper and nodular iron.

Quality assurance

- The canister fabrication work is being conducted in accordance with the requirements in ISO 9001 and 14001. The activities are described in detail in the existing canister fabrication manual with appurtenant fabrication drawings, technical specifications and procedure descriptions. The quality system is being developed continuously and appurtenant documents are revised as needed.

- An important area is establishing acceptance criteria for all parts of the canister, including any welds. Such criteria are material requirements and acceptance limits for both superficial defects and defects inside the material. A consequence analysis should be carried out showing what happens if there are more or larger defects than stipulated by the acceptance criteria.
- Relevant fabrication processes and inspection and testing procedures must be qualified. This work will be systematized and pursued during the next few years.

Canister factory

- The lessons learned from the trial fabrication of all canister parts will be applied to and influence the further development of the factory. The work of researching and establishing acceptance criteria and testing methods will make it possible to specify modified equipment for NDT and other quality inspection more precisely. A more thorough evaluation of modified machinery and testing equipment will be made in cooperation with potential suppliers. This will provide opportunities for a more precise analysis of the factory's layout and investment costs.
- If the development of FSW shows that the technique may be suitable for canister fabrication, the consequences of this need to be examined and weighed into factory layout and investment costs.
- The ongoing study of environmental impact in connection with canister fabrication will be concluded.
- One step in the ongoing work of development of the quality system for canister fabrication is finding the necessary network of suitable subcontractors and creating a long-term and businesslike relationship with them. In conjunction with ongoing trial fabrication, continuous assessment of suppliers will take place through regular quality audits and analysis of pricing, delivery reliability and probable future development.
- In order to get a complete picture of potential uncertainties, a risk analysis will be conducted of operations in the planned canister factory.

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Appendix 1

List of SKB's Technical Specifications

Inkapslingsteknik –
Kapseltillverkning
Sida nr 1 (1)

Rev nr 4
Giltig från 2003-03-13
Granskad av
Godkänd av

Förteckning över SKB Tekniska specifikationer

Docqa reg.nr 3425-2572

Förteckning över SKB Tekniska specifikationer

Nummer	Rubrik	Rev
KTS001	Copper Ingots and Billets for Canister Components	4
KTS002	Copper Components for Canisters	1
KTS003	Welding Procedure Specification for Copper Base	0
KTS011	Nodular Cast Iron EN 1563 Insert	3
KTS012	Steel Lid for Canister	1
KTS021	Steel Section Cassette	3
KTS022	Profiles for Steel Section Cassette	1
KTS031	Assembly of Canister in the Trial Stage of Manufacture	0

Appendix 2

Technical Specification KTS 001 “Copper Ingots and Billets for Canister Components”

Docqa reg. nr 3425-2572

Technical Specification No KTS001

Copper Ingots and Billets for Canister Components

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Technical Specification No KTS001

Copper Ingots and Billets
for Canister Components

Revision No 4
Valid from 13 Mar 2003
Prepared by
Reviewed by
Approved by

Docqa reg. nr 3425-2572

KTS001 Copper Ingots and Billets for Canister Components

1 Purpose

Copper ingots and billets are used for production of copper components to canisters [1]. This technical specification, KTS001, defines technical requirements and documentation procedures for copper ingots, including continuously cast billets, for this purpose.

2 Technical requirements

2.1 Material specification

The material for copper canisters shall fulfil the specification in EN 1976:1988 [2] for the grades Cu-OFE (Table 2) or Cu-OF1 (Table 3) with the following additional requirements: O < 5 ppm, P 30–70 ppm, H < 0,6 ppm, S < 8 ppm.

2.2 Chemical composition

Table 1. Requirements and comments concerning various properties

Property	Specification	Comments
Weldability	O < 5 ppm	Higher levels give a reduced weldability.
Ductility	H < 0,6 ppm	Higher levels give reduced mechanical properties. (Hydrogen embrittlement).
Tensile strength, ductility	S < 8 ppm	Higher levels give reduced mechanical properties caused by non-dissolved sulphur which will be concentrated to grain boundaries.
Creep ductility	P 30–70 ppm	A phosphorus content of this order reduces the influence of sulphur impurities, increases creep ductility, increases recrystallisation temperature and has a minor influence on the weldability.

Note: The P content in Table 1 is required for the canister application. It is substantially higher than in the standard referred to in Table 2 on the next page.

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[1] SKB Technical Specification KTS002, Copper components for canisters

[2] EN 1976:1988, Copper and copper alloys – Cast unwrought copper products

Table 2. EN 1976 Cu-OFE composition (UNS C10100[3])

Element	Cu	Ag	As	Fe	S	Sb	Se	Te	Pb
	%	ppm b)	→						
	99,99 a)	25	5	10	15	4	3	2	5
	P	Bi	Cd	Mn	Hg	Ni	O	Sn	Zn
	ppm b) →								
	3	1	1	0,5	1	10	5	2	1

Table 3. EN 1976 Cu-OF1 composition

Element	Cu	Ag	As	Fe	S	Sb	Se	Te	Pb
	(rem.)	ppm	→						
		25 b)	5 c)	10 d)	15 b)	4 b)	2 e)	2 f)	5 b)

a) Including Ag
b) Maximum content
c) Σ As + Cd + Cr + Mn + Sb $\leq$ 15 ppm
d) Σ Co + Fe + Ni + Si + Sn + Zn $\leq$ 20 ppm
e) Σ Bi + Se + Te $\leq$ 3 ppm
f) Σ Se + Te $\leq$ 3,0 ppm

2.3 Size and tolerances

Delivery weight, size and surface condition of ingots and continuously cast billets shall be as stated in the SKB order.

2.4 Macroscopic discontinuities

Experience is being collected to determine permissible types and extent of discontinuities.

2.5 Identification marking

Each copper ingot or continuously cast billet shall be marked with the producer’s cast number and any additional requirements in the SKB order. The top end of each ingot intended for tubes shall be marked TOP. No marking is needed on the bottom end.

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[3] UNS C10100 according to Application Datasheet, Standard Designation for Wrought Alloys, www.copper.org

2.6 Sampling

Sampling for chemical analysis and any other testing shall be described in a sketch.

Ingots

Samples shall be taken from representative material of cut-off ends.

Continuously cast billets

The manufacturer's normal sampling method shall be applied. Additional samples for P test shall be taken at least from the start and final ends of a casting intended for forged blanks, unless other sampling is agreed with SKB.

3 Inspection and testing

3.1 Chemical analysis

The analysis shall be performed in accordance with industry practice by an accredited laboratory or by a laboratory meeting at least ISO 9002:1994 [4] requirements.

Laboratory reference material shall be traceable to accredited sources and its identity and use for the analysis shall be recorded.

3.2 Visual inspection

The manufacturer shall inspect the ingots and billets visually for surface defects, for example cracks or flaws, particularly at the centre of the ingot end surfaces. The result shall be recorded. Further inspection as specified in the SKB order.

4 Supplier's documentation

4.1 Certification of copper ingots and cast billets

The copper ingot/billet manufacturer shall issue a certificate according to EN 10204 3.1.B [5] or declaration of conformity according to EN 1655 Type C or Type D [6], stating as a minimum:

- the manufacturer's name and address,
- date of issue,
- SKB order and specification numbers,

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[4] ISO 9002:1994, Quality systems – Model for quality assurance in production, installation and servicing

[5] EN 10204:1995, Metallic products – Types of inspection documents

[6] EN 1655:1997, Copper and copper alloys – Declaration of conformity

- heat or cast number,
- copper ingot or billet dimensions and weight,
- applicable standard,
- chemical composition,
- result of visual inspection,
- illustrated description or sketch of sampling of solid material,
- a declaration that the material has been produced in accordance with the manufacturer's own current quality system, accepted by SKB,
- any other requirement specified in the SKB order.

4.2 Submission of documents and information

The certificate according to 4.1 and request for delivery permit[7] shall be sent to SKB by mail or telefax for authorization prior to dispatching the copper ingot or billet for hot working.

The manufacturer shall, without delay, give complete information to SKB on all observations and other circumstances in connection with the production, which may influence the design and properties of the copper canister. SKB shall have the right to use this information without any restriction.

4.3 Retention of documentation

QA Co-ordinator Canister Manufacturing Technique, QASK, is responsible for the retention of documentation according to sections 2, 3 and 4, described in a separate procedure[8].

The manufacturer shall retain the documentation according to sections 2.6 and 3.1 for (presently) at least 10 years under suitable security. If any records are stored on electronic/magnetic media the readability shall be ensured for this time period.

5 Retention of test samples

The manufacturer shall retain samples for determination of the chemical composition for (presently) minimum 10 years under suitable conditions. The identification of samples shall be maintained. SKB shall be contacted prior to subsequent discarding of any test samples.

6 Document control

QASK is responsible for document control, including distribution, of this technical specification[9].

[7] SKB Form KTF07-07 or KFT07-08 or similar
[8] SKB Procedure KT1002, Retention of quality documents and records
[9] SKB Procedure KT1001, Establishing and control of SKB procedures and technical specifications

Appendix 3

Technical Specification KTS 002 “Copper Components for Canisters”

Docqa reg. No 3425-2572

Technical Specification No KTS002

Copper Components for Canisters

Table of Contents

KTS002 Copper Components for Canisters

1 Purpose

Copper blanks for lids or bases are manufactured by forging, and seamless copper tubes are produced by the pierce and draw process, extrusion or forging. This technical specification, KTS002, defines technical requirements and documentation routines for those components.

Note: An alternative tube manufacturing process includes roll forming and longitudinal welding of copper plate. When applicable, details of the process will be specified separately.

2 Technical requirements

2.1 Material specification

The starting copper billet and ingot material for hot working to components for canisters shall fulfil requirements in a separate specification [1].

2.2 Grain size and mechanical properties

Forged copper blanks and seamless copper tubes shall have a grain size less than the limit specified in Table 1, see next page. The grain size is to be determined according to EN ISO 2624 [2], using the comparison, intercept or planimetric procedure.

Note: The standard grain size chart for the comparison method showing the structure for 0,120 mm (120 μm) average grain diameter at 75x magnification can be used for 360 μm grain size at 25x magnification.

Note: The grain size specified in Table 1 generally refers to the maximum average grain size as determined according to EN ISO 2624. However, in some instances the structure of hot worked copper will comprise relatively few large grains in a matrix of fine grains. In such cases the maximum size refers to individual grains as seen in a prepared sample surface. Experience is being collected to determine acceptance limits regarding this type of structure.

2.3 Macroscopic discontinuities

Experience is being collected to determine acceptance criteria for internal and surface defects of copper blanks and tubes. See also 5.1.

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[1] SKB Technical Specification KTS001, Copper ingots and billets for canister components

[2] EN ISO 2624:1995, Copper and copper alloys – Estimation of average grain size

Revision No	1
Valid from	13 Mar 2003
Prepared by	M Westman
Reviewed by	L Werme
Approved by	C-G Andersson

Copper Components for Canisters

Table 1. Requirements and comments concerning grain size and mechanical properties in hot formed material.

Property	Specification	Comments
Microstructure in forged copper blanks	Grain size < 360 µm	This grain size gives a resolution at ultrasonic testing comparable to X-ray testing of 50 mm thick copper.
Microstructure in seamless copper tubes	Grain size < 360 µm	Same comment as above.
Ductility	Elongation > 40% RT–100°C	The canister will be deformed 4% in final repository.
Creep ductility	Elongation at creep-rupture > 10% RT–100°C	Same comment as above.

2.4 Size and tolerances

Forged copper blank for base or lid

Nominal weight, size, shape and surface condition according to the SKB order and applicable drawing.

Seamless copper tube

Length, diameter, wall thickness, surface condition and tolerances according to the SKB order and applicable drawing.

2.5 Identification marking

Each forged copper blank or copper tube shall be marked in accordance with requirements in the SKB order and applicable procedure [3].

3 Hot forming process

The hot forming process shall be performed in such a manner that the specified properties of the delivered product are met. The process shall be controlled and documented by the manufacturer of copper blanks or tubes to the extent necessary for ensuring reproducibility. It shall be ensured that appropriate, identified tools or equipment are selected and used. This shall be suitably documented.

---

[3] SKB Procedure KT0705, Identification of canister components and assembled canisters

Note: If an accepted ingot shows minor line cracks, pores or other inhomogeneities in one end surface, that end shall be the base end when upset forging and piercing is applied.

4 Machining

4.1 Copper lid

Machining of each blank for copper lids shall be performed in accordance with applicable SKB drawings, normally in two steps, pre-machining to a rough shape and final machining to the end shape.

4.2 Copper base

Machining of each blank for copper bases shall be performed in accordance with applicable SKB drawings normally in two steps, pre-machining to a rough shape and machining to the shape necessary for welding.

Final machining shall be carried out after welding of the base to the copper tube in accordance with applicable SKB drawings.

4.3 Copper tube

Machining of all surfaces of each copper tube shall be performed after hot forming to size and shape as stated in applicable SKB drawings. When welding of base to the tube is applied (such as for extruded or forged tube), the final machining of the top end shall be performed after the base-to-tube welding, since the tube length may be affected by the welding.

5 Inspection and testing

5.1 Visual inspection and non-destructive testing

The copper blank or tube shall be inspected visually and by 100% non-destructive testing. Experience is being collected to determine methods to be applied, sizes and shapes of reference defects, which will be stated in separate procedures. Result of the examination shall be recorded.

Qualification of NDT including methods, procedures and personnel for this purpose is described in a separate procedure[4].

---

[4] SKB Procedure KT0605, Qualification process for NDT of canister components

5.2 Sampling for determination of mechanical properties and structure

All sampling is to be described in the quality plan in agreement with SKB[5].

5.3 Mechanical properties

Test pieces for tensile testing (Rp 0,2; Rm; A 50 mm) preferably according to EN 1563:1997[6], shall be taken from tubes and from blanks for lids and bases as specified by SKB.

Tensile testing shall be performed in accordance with EN 10002-1[7] by an accredited laboratory or by a laboratory meeting at least ISO 9002:1994[8] requirements. Test records shall be retained.

5.4 Structure

Specimens for grain size/structure inspection shall be taken from each blank for lid or base and tube. The structure shall be documented by photos at approximately 25x magnification.

Blank for lid or base

Grain size/structure shall be determined close to the surface or rim and also, when specified in the SKB order, in the centre of the material. The centre part refers to the surface of the blank centre.

Tube

Grain size/structure shall be determined at both tube ends close to the envelope surface and also in the centre of the material, unless otherwise specified in the SKB order.

Experience is being collected regarding the possibility to determine the copper grain size from ultrasonic parameters.

5.5 Photographic documentation

The production sequence shall be photographically documented when required by SKB. The extent is to be agreed with SKB from case to case.

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[5] Requirements on sampling, including sample positions, may be added in a later revision of this document.
[6] EN 1563:1997, Founding – Spheroidal graphite cast iron
[7] EN 10002-1:2001 – Metallic materials – Tensile testing
[8] ISO 9002:1994, Quality systems – Model for quality assurance in production, installation and servicing

6 Manufacturer’s documentation

6.1 Material certificate

The copper blank or copper tube manufacturer shall issue a certificate according to EN 10204 3.1.B[9], or declaration of conformity according to EN 1655 Type C or D[10], stating or including as a minimum:

- the manufacturer’s name and address,
- date of issue,
- SKB order number,
- applicable SKB drawing and specification numbers, including revisions,
- original heat or cast number,
- lot number and/or number of the blank or tube,
- dimensions of the blank or tube,
- results of non-destructive testing,
- results of tensile testing when applicable, and determination of grain size and structure,
- illustrated description of sampling[5],
- a declaration that the component has been produced in accordance with the company’s own current quality system,
- any other requirement specified in the SKB order.

6.2 Submission of documents and information

The certification according to 6.1 and request for delivery permit[11] shall be sent to SKB for authorization prior to delivery of the blank or tube.

The supplier shall, without delay, give complete information to SKB on all observations and other circumstances in connection with the production, which may influence the design and properties of the components and/or the copper canister. SKB shall have the right to use this information without any restriction.

6.3 Retention of documentation

QASK is responsible for the retention of documentation according to sections 5 and 6, described in a separate procedure[12].

The manufacturer shall retain the documentation according to sections 5 and 6 for (presently) at least 10 years under suitable security. If any records are stored on electronic/magnetic media the readability shall be ensured for this time period.

---

[9] EN 10204:1995, Metallic products – Types of inspection documents
[10] EN 1655:1997, Copper and copper alloys – Declaration of conformity
[11] SKB Form KTF07-07 or KTF07-08 or similar
[12] SKB Procedure KT1002, Retention of quality documents and records

Technical Specification No KTS002	Revision No	1
	Valid from	13 Mar 2003
	Prepared by	M Westman
Copper Components for Canisters	Reviewed by	L Werme
	Approved by	C-G Andersson

Docqa reg. No 3425-2572

7 Retention of test samples

The manufacturer shall retain samples for determination of microstructure and, when applicable, tensile properties for (presently) minimum 10 years under suitable conditions. The identification of samples shall be maintained. SKB shall be contacted prior to subsequent discarding of any test samples.

8 Document control

QA Co-ordinator Canister Manufacturing Technique is responsible for document control, including distribution, of this technical specification [13].

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[13] SKB Procedure KT1001, Establishing and control of SKB procedures and technical specifications

Appendix 4

Technical Specification KTS 011 "Nodular Cast Iron EN 1563 Insert"

Docqa reg. nr 3425-2572

Technical Specification No KTS011

Nodular Cast Iron EN 1563 Insert

Table of Contents

Docqa reg. nr 3425-2572

KTS011 Nodular Cast Iron EN 1563 Insert

1 Purpose

Cast iron inserts are essential canisters components. This technical specification, KTS011, defines the technical requirements and documentation for nodular cast iron inserts.

2 Technical requirements

2.1 Material specification

The material for nodular cast iron inserts shall fulfil the requirements in EN 1563[1] grade EN-GJS-400-15U (Number EN-JS1072, SS 07 17-00) regarding mechanical properties. The specified mechanical properties for dimension 60< t ≤200 mm (R_m min 370 N/mm^2, $R_{p0,2}$ min 240 N/mm^2, A min 11%) shall apply for specimens from any position of the casting.

The chemical composition given as information in SS 14 07 17[2] may be adjusted, if necessary. Experience is being collected to determine if any change of the specification is required.

2.2 Microstructure

At all positions of the casting, the microstructure shall correspond, to a minimum of 80%, to forms V and VI in EN ISO 945[3]. The nodule count shall be minimum 100 nodules/mm^2 determined at 100x magnification.

The microstructure shall nowhere be as illustrated by forms I – III.

2.3 Macroscopic discontinuities

Experience is being collected to determine permissible types end extent of discontinuities such as non-metallic and other types of inclusions, cold flows, gas porosities, shrinkage cavities and shrinkage cracks.

2.4 Size and shape

Size and shape of inserts shall be as stated in drawings according to applicable SKB order. See 6.3 for corresponding inspection requirements.

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[1] EN 1563:1997, Founding – Spheroidal graphite cast iron

[2] SS 14 07 17:1981, Segjärn – SS-gjutjärn 0717 (Speroidal graphite iron)

[3] EN ISO 945:1994, Cast iron – Designation of microstructure

2.5 Identification marking

Each cast insert shall be marked in accordance with requirements in the SKB order and applicable procedure [4]. This identification shall be maintained throughout the manufacture, including the machining stages.

3 Steel section cassette [5]

The cassette hollow sections shall be shot blasted inside and outside to remove oxide and shall be stored under dry conditions to prevent rusting. The shot blasting shall be done as closely in time as possible prior to casting. The steel section cassette shall be filled with a suitable filler to prevent distortion during casting.

4 Casting

The casting process shall be controlled to ensure an acceptable structure. This shall include recording of melting parameters such as tapping temperature, temperature for Mg addition and inoculation, time elapsed between Mg addition and pouring, pouring temperature and time. This shall be described in an internal work instruction, available at the melt shop.

Samples for chemical analysis shall be taken after Mg treatment in accordance with normal practice.

5 Machining and weld repair

5.1 Cutting of ends and test disk

Cutting of insert ends, including any test disk, shall be performed by suitable means, e.g. bandsaw cutting. It is recognised that cooling liquids have to be used, efforts shall be taken, however, to minimise exposure of insert surfaces, in particular the top end of cassette sections to water or any other liquid.

5.2 Rough machining and cleaning from filler medium, e.g. sand

Cleaning the channel surfaces from remainder of the filler medium, e.g. sintered sand particles can be performed by adding tumbling media in the channels during the rough turning operation. Afterwards the channels shall be properly cleaned from dust etc.

Rough machining of the insert circumference and the recess for steel lid shall be done without any cooling liquid.

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[4] SKB Procedure KT0705, Identification of canister components and assembled canisters

[5] SKB Technical Specification KTS021, Steel section cassette

5.3 Weld repair

Weld repair of defects on the insert circumference is currently permissible but is expected to lead to the following restrictions for an individual insert:

- any defect area maximum xx cm^2
- total defect area maximum xx dm^2
- any defect depth maximum xx mm
- welding filler metal = xx

(xx = data to be developed)

Any repair welding larger than xx cm^2 is to be recorded indicating size and also length and circumferential position from a reference mark.

A Welding Procedure Specification shall be developed and applied for repair welding.

Until sufficient experience of weld repairs have been accumulated the manufacturer shall request concession from SKB prior to performing any repair[6].

6 Inspection and testing

6.1 Chemical analysis

The analysis shall be performed in accordance with industry practice by an accredited laboratory or by a laboratory meeting at least ISO 9002[8] requirements. Laboratory reference material shall be traceable to accredited sources and its identity and use for the analysis shall be recorded.

6.2 Tensile testing and microstructure evaluation

Sampling

Test pieces for tensile and hardness testing and for microstructure examination shall be taken as specified in the SKB order. A sketch of the actual sample size and position(s) shall be provided.

Tensile testing

Tensile testing shall be performed in accordance with EN 10002-1[7] by an accredited laboratory or by a laboratory meeting at least ISO 9002[8] requirements. Test records shall be retained. Requirements for mechanical properties shall be as specified in 2.1.

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[6] SKB Procedure KT1102, Request for concession
[7] EN 10002-1:2001, Metallic materials – Tensile testing
[8] ISO 9002:1994, Quality systems – Model for quality assurance in production, installation and servicing

Hardness testing

Hardness testing – HB according to EN ISO 6506-1 [9], preferably using 10 mm ball – shall be performed on the test pieces from cast-on samples and the result shall be recorded.

Microstructure

Microstructure evaluation shall also be performed on the test pieces from cast-on samples. The structure shall be documented in micrographs at 100x magnification.

6.3 Size and shape inspection

The casting shall be measured to check its conformity with the specified size.

For BWR fuel canister inserts with cassettes made from square sections (VKR) 180 x 180 x 10 mm (outer size x thickness) the straightness of the channels shall be sufficient to permit a 152 x 152 mm square profile test-gauge in accordance with applicable SKB drawing to freely move down the entire channel.

In case the 152 x 152 mm test-gauge does not pass down the entire channel

1) the distance that the test-gauge can be freely moved down is to be measured for various diminishing sizes from 152 x 152 mm,
2) to verify the largest size that will pass the entire channel.

The result shall be documented on a separate form [10].

For PWR fuel canister inserts with cassettes sections 250 x 250 x 10 mm the corresponding test-gauge size is 224 x 224 mm. Corresponding testing and recording shall be performed.

Maximum permissible excentricity of the machined insert is to be determined later on. The excentricity will be defined as the distance between centre of the cassette and the centre of the casting at the same height, measured as well at the bottom end as at the top end of the insert. The methods of measurement and the results are to be recorded.

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[9] EN ISO 6506-1:1999, Metallic materials – Brinell hardness test – Part 1:Test method

[10] SKB Forms KTS001F-1, KTS001F-2, KTS001F-3 or similar

6.4 Non-destructive testing

The casting shall be 100% tested from the outside with regard to inner discontinuities such as non-metallic inclusions and other inhomogeneities. Experience is being collected to determine suitable NDT method as well as size and shape of reference defect and acceptance criteria, which will be stated in a separate procedure or in the SKB order. Qualification of NDT including methods, procedures and personnel for this purpose is described in a separate procedure[11].

The structure is to be checked using measurement of ultrasonic damping and speed of sound to collect experience of the possibility to determine the homogeneity.

7 Final machining

Final machining shall be done in accordance with applicable SKB drawing. The machining shall be done in the dry condition, i.e. without any cooling liquid.

8 Transport and storage protection

To prevent exposure to snow, water, dust, dirt etc. during any outdoor transport and storage the insert and in particular the channel ends shall be suitably protected, e.g. by plastic cover. However, rust preventive liquids are not permitted. Long range transports shall be performed on covered trucks, lorries, railway trucks etc. See also a separate procedure[12].

9 Manufacturer’s documentation

9.1 Photographic documentation

The production sequence shall be photographically documented when required by SKB. The extent is to be agreed with SKB from case to case.

9.2 Certification

A certificate according to EN 10204 3.1.B[13] shall be issued by the manufacturer stating as a minimum:

- the manufacturer’s name and address,
- SKB order number,
- SKB drawing number,
- insert number,

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[11] SKB Procedure KT0605, Qualification process for NDT of canister components

[12] SKB Procedure KT0702, Handling, storage, packing and transport of canister components and assembled canisters

[13] EN 10204:1995, Metallic products – Types of inspection documents

- casting date,
- cast or heat number,
- chemical composition,
- results of tensile testing, hardness testing and micro structure evaluation,
- result of size and shape inspection,
- result of non-destructive testing,
- a declaration that the material has been produced in accordance with the company's own current quality system, accepted by SKB.

9.3 Submission of documents and information

The documentation according to 5.3, 6 and 9.2 and request for delivery permit [14] shall be sent to SKB for authorisation prior to delivery.

The supplier shall, without delay, give complete information to SKB on all observations and other circumstances in connection with the production which may influence the design and properties of the insert. SKB shall have the right to use this information without any restriction.

9.4 Retention of documentation

QA Co-ordinator Canister Manufacturing Technique, QASK, is responsible for the retention of documentation according to sections 5, 6 and 9 described in a separate procedure [15].

The manufacturer shall retain the documentation according to sections 4, 5, 6 and 9 for (at present) at least 10 years under suitable security. If any records are stored on electronic/magnetic media the readability shall be ensured for this time period.

10 Retention of test samples

The casting producer shall retain samples for determination of chemical composition, microstructure and tensile properties for (at present) minimum 10 years under suitable conditions. The identification of samples shall be maintained. SKB shall be contacted prior to subsequent discarding of any test samples.

11 Document control

QASK is responsible for document control, including distribution, of this technical specification [16].

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[14] SKB Form KTF07-07 or KTF07-08 or similar
[15] SKB Procedure KT1002, Retention of quality documents and records
[16] SKB Procedure KT1001, Establishing and control of SKB procedures and technical specifications

Appendix 5

Technical Specification KTS 012 “Steel Lid for Canister Inserts”

Docqa reg. nr 3425-2572

Technical Specification No KTS012

Steel Lid for Canister

Table of Contents

KTS012 Steel Lid for Canister

1 Purpose

Steel lids for canister inserts are produced from steel plates. This technical specification, KTS012 defines technical requirements and documentation routines applicable to such steel lids.

2 Technical requirements

2.1 Material specification

Plate according to EN 10025 S355J2G3, SS 14 21 72 [1], or similar grade with at least the same tensile strength and ductility, in the as hot rolled or normalised condition shall be used. Chemical composition and tensile strength shall meet requirements defined in the standard.

2.2 Size and tolerances

Shape, diameter, thickness and surface finish shall meet requirements in applicable drawing as stated in the SKB order.

2.3 Macroscopic discontinuities

Experience is being collected to determine acceptance criteria regarding defects, which will be stated in a separate procedure or in the SKB order.

2.4 Identification marking

Each plate shall be given a unique marking as required in the SKB order and a separate procedure [2].

3 Inspection and testing

3.1 Size and shape, surface finish

Diameter, thickness and skewness etc. are to be determined in accordance with normal industry practice. The surface finish shall be visually inspected.

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[1] SS 14 21 72:1990, Structural steel – SS-steel 21 72

[2] SKB Procedure KT0705, Identification of canister components

3.2 Non–destructive testing

The plate shall be controlled by non-destructive testing. Experience is being collected to determine suitable NDT method as well as size and shape of reference defect. Qualification of NDT including methods, procedures and personnel for this purpose is described in a separate procedure [3].

3.3 Mechanical properties

No specific tensile testing (i.e. testing specimens from the current plate or from the lot of which the plate is a part) is required. The manufacturer shall, however, be able to show evidence that plate of the present size, manufactured under similar conditions, will meet the requirements specified in the standard [4].

4 Manufacturer's documentation

4.1 Material certificate

The plate manufacturer shall issue a certificate according to EN 10204 2.2 or 3.1.B [5], stating as a minimum:

- the manufacturer's name and address,
- date of issue,
- reference to applicable material/product standard,
- steel grade and execution,
- dimensions,
- for EN 10204 2.2 certificate in addition:
  - typical chemical composition; or
- for EN 10204 3.1.B certificate in addition:
  - original heat or cast number,
  - actual chemical composition of the heat or cast.

4.2 Lid manufacturer's documentation

The lid manufacturer shall issue documentation stating as a minimum

- SKB order number or applicable subcontractor's order number,
- SKB specification number,
- identification (number) of the lid,
- result of measurement of size and shape,
- results of non-destructive testing, if any,
- a declaration that the material has been produced in accordance with the manufacturer's own current quality system,
- any other requirement specified in the SKB order.

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[3] SKB Procedure KT0605, Qualification process for NDT of canister components

[4] Requirements on specific testing, including sampling, may be added in a later revision of this document.

[5] EN 10204:1995, Metallic materials – Types of inspection documents

4.3 Submission of documents and information

The material certificate according to 4.1 shall be sent to the lid manufacturer for check of compliance with standard.

The lid manufacturer shall send the documentation according to 4.1 and 4.2 and request for delivery permit[6] to SKB for authorization prior to delivery of the lid.

The lid manufacturer shall, without delay, give complete information to SKB on all observations and other circumstances in connection with the production, which may influence the design of the canister components. SKB shall have the right to use this information without any restriction.

4.4 Retention of documentation

QA Co-ordinator Canister Manufacturing Technique, QASK, is responsible for the retention of documentation according to sections 4.1, and 4.3, described in a separate procedure[7].

The manufacturer shall retain the documentation according to sections 4.1 and 4.2 for at least 10 years under suitable security. If any records are stored on electronic/magnetic media the readability shall be ensured for this time period.

5 Document control

QASK is responsible for document control, including distribution, of this technical specification[8].

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[6] SKB Form KTF07-07 or KTF07-08 or similar

[7] SKB Procedure KT1002, Retention of quality documents and records

[8] SKB Procedure KT1001, Establishing and control of SKB procedures and technical specifications

Technical Specification KTS 021 “Steel Section Cassette”

Technical Specification No KTS021

Steel Section Cassette

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Technical Specification No KTS021

Steel Section Cassette

Revision No 3
Valid from 13 Mar 2003
Prepared by
Reviewed by Lars Werme
Approved by

Docqa reg. No 3425-2572

KTS021 Steel Section Cassette

1 Purpose

Steel section cassettes are used in the production of cast iron canister inserts. This technical specification, KTS021, defines the technical requirements and documentation procedures applicable to the manufacture of steel section cassettes, intended for that purpose.

2 Technical requirements

2.1 Properties

The technical requirements, including steel grade, size and tolerances, of square hollow sections[1] and other steel parts for the manufacture of steel section cassette are given in a separate specification[2].

2.2 Identification

The completed cassette shall be traceable to the heat or cast of the square hollow sections. The identification method used is at the discretion of the party ordering the cassette. One possible identity marking method would be to use the number of the insert for which the cassette is intended, described in a separate procedure[3].

2.3 Macroscopic discontinuities

No defects, such as cracks and incomplete welds, are permitted anywhere in the cassette leading to risk for penetration of nodular cast iron into the channels in the subsequent use. Any defects of such a type shall be repaired by welding and subsequently inspected by the manufacturer.

3 Production

3.1 Drawings

Drawings according to the applicable SKB order shall be used for the manufacture of cassettes.

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[1] Hot finished square structural hollow sections (Varmbearbetade konstruktionsrör)
[2] SKB Technical Specification KTS022, Profiles for steel section cassette
[3] SKB Procedure KT0705, Identification of canister components

3.2 Manufacture of steel section cassette

The cassette shall be assembled by welding. The selection of welding method including welding consumables is at the discretion of the manufacturer but shall follow a welding procedure specification (WPS), issued by the manufacturer. Precautions shall be taken to prevent deformation of the sections as well as burning-through during the welding operation.

3.3 Treatment and preservation

The cassette hollow sections shall be shot blasted inside and outside to remove oxide and shall be stored under dry conditions to prevent rusting. This also applies to any transport or storage of the assembled cassette. The shot blasting shall be done as closely in time as possible prior to casting.

4 Inspection and testing

4.1 Size and shape inspection

The completed manufactured cassette shall be measured to check its conformity with the specified size and shape. For insert cassettes made from square sections (VKR) 180 x 180 x 10 mm (outer size x thickness) the straightness of the channels shall be sufficient to permit a 156 x 156 mm square profile test-gauge, manufactured according to the applicable SKB drawing, to freely move down the entire channel.

For cassettes made from 250 x 250 x 10 mm sections the corresponding square profile test-gauge shall be 226 x 226 mm.

Note: Square sections with a different wall thickness may also be tested for cassettes.

4.2 Inspection of welds

The complete, welded cassette shall be visually inspected for welding defects. Requirements, see 2.3.

5 Manufacturer's documentation

5.1 Steel section certificate

The cassette manufacturer shall request a certificate from the steel section supplier in accordance with a separate SKB specification[2].

5.2 Photographic documentation

The cassette manufacture shall be photographically documented when required by SKB. The extent is to be agreed with SKB from case to case.

5.3 Other documentation

The cassette manufacturer shall issue a report describing
- result of size and straightness inspection,
- result of visual inspection of welds.

The result of size and straightness inspection shall be recorded on a separate form[4].

5.4 Submission of documents and information

The party receiving the SKB order (foundry or cassette manufacturer) shall submit the documentation mentioned in 5.1, 5.2 and 5.3 to SKB.

The supplier shall also, without delay, give complete information to SKB and to the foundry concerned on all observations and other circumstances in connection with the production, which may influence the design or properties of the cassette. SKB shall have the right to use this information without any restriction.

5.5 Retention of documentation

QA Co-ordinator Canister Manufacturing Technique, QASK, is responsible for the retention of documentation according to section 5, described in a separate procedure[5].

The manufacturer shall retain the documentation according to sections 5.1, 5.2 and 5.3 for (at present) at least 10 years under suitable security. If any records are stored on electronic/magnetic media the readability shall be ensured for this time period.

6 Document control

QASK is responsible for document control, including distribution, of this technical specification[6].

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[4] SKB Forms KTS001F-1, KTS001F-2, KTS001F-3 or similar
[5] SKB Procedure KT1002, Retention of quality documents and records
[6] SKB Procedure KT1001, Establishing and control of SKB procedures and technical specifications

Technical Specification KTS 022 “Profiles for Steel Section Cassette”

Docqa reg. nr 3425-2572

Technical Specification No KTS022

Profiles for Steel Section Cassette

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Technical Specification No KTS022

Profiles for Steel Section Cassette

Revision No 1
Valid from 13 Mar 2003
Prepared by
Reviewed by
Approved by

Docqa reg. No 3425-2572

KTS022 Profiles for Steel Section Cassette

1 Purpose

Profiles according to this technical specification are intended for use in steel section cassettes. This technical specification, KTS022, defines technical requirements and documentation routines applicable to profiles and other steel parts for that propose.

2 Technical requirements

Profiles for steel sections cassettes are either hot or cold formed square hollow sections, designations VKR[1] and KKR[2] respectively. Seamless sections as well as welded sections can be used. In the latter case the weld bead shall be flush against the section inner wall, if necessary machined.

2.1 Material specification for VKR (RHS[3]) square hollow sections

The material for VKR (RHS) square hollow sections shall fulfil the requirements in EN 10015 S355J2H or SS 14 21 34-03 or -04[4], concerning chemical composition and mechanical properties (Re_L, R_m, A_5).

For BWR fuel canisters 180 x 180 x 10 mm (outer size [H x B] x thickness [t]) VKR square hollow section size applies, and for PWR fuel canisters the corresponding size is 250 x 250 x 10 mm.

Size and shape tolerances, based on EN 10210-2[5]:

- H, B: 180 ±1,8 mm for BWR
  250 ±2,5 mm for PWR
- t: 10 -1 + a) mm
- squareness: 90° ± 1°
- flatness deviation: ≤ 1,8 mm for BWR (across section, concavity/convexity)
  ≤ 2,5 mm for PWR - " -
- twist: max 2 mm +0,5 mm/m section length
- outer corner radius: 25 ±5 mm b)
- length: +10 -0 mm
- straightness: 0,20% of total length
- mass ±6% c)

a) The positive deviation is limited by the tolerance on mass.
b) Minimum radius added.
c) -6 +8% for seamless hollow sections

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[1] Hot finished square structural hollow sections (Varmbearbetade konstruktionsrör)
[2] Cold formed welded structural hollow sections (Kallformade svetsade konstruktionsrör)
[3] Rectangular hollow sections
[4] SS 14 21 34:1993, Structural steel – Microalloyed steel – SS-steel 21 34
[5] EN 10210-2:1998, Hot finished structural hollow sections of non-alloy and fine grain structural steels

2.2 Material specification for KKR[1] square hollow sections

The material for KKR square hollow sections shall fulfil the requirements in EN 10015 S355J2H or SS 14 21 34-03 or -04[3], concerning chemical composition and mechanical properties (Re_L, R_m, A_5).

For BWR fuel canisters 180 x 180 x 10 mm (outer size [H x B] x thickness [t]) KKR square hollow section size applies, and for PWR fuel canisters the corresponding size is 250 x 250 x 10 mm.

Size and shape tolerances, based on EN 10219-2[6]:

- H, B: 180 ±1,4 mm for BWR
  250 ±1,5 mm for PWR
- t: 10 ±0,5 mm
- squareness: 90° ±1°
- flatness deviation: ≤ 1,4 mm for BWR (across section, concavity/convexity)
  ≤ 2,0 mm for PWR (across section, concavity/convexity)
- twist: max 2 mm +0,5 mm/m section length
- outer corner radius: 25 ±5 mm
- length: +10 -0 mm
- straightness: 0,15% of total length

Note: Square hollow sections with a different wall thickness may also be tested for cassettes. Size and shape tolerances will in such cases be specified in the SKB order.

2.3 Material specification for plates and flat bars

The material for steel plates and flat bars shall fulfil the requirements in EN 10025 S235JRG2, SS 14 13 12[7] or similar. The surface shall be free from contaminants such as rust and dirt.

Plate and bar sizes are specified on applicable SKB drawings.

2.4 Macroscopic discontinuities

No defects, such as cracks or incomplete welds in welded hollow sections, leading to risk for penetration of nodular cast iron in the subsequent use, are permitted.

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[6] EN 10219-2:1998, Cold formed welded structural hollow sections of non-alloy and fine grain steels

[7] SS 14 13 12:1990, Structural steel – SS-steel 13 12

3 Inspection and testing of square hollow sections

3.1 Size and shape inspection, surface finish

Outer size, thickness, straightness and twist are to be checked for compliance with applicable standard. For square hollow sections (VKR or KKR) 180 x 180 x 10 mm (outer size x thickness) the shape and straightness of the sections shall be sufficient to permit a 156 x 156 mm square profile test-gauge, manufactured according to applicable SKB drawing, to freely move down the entire channel length. The result shall be recorded[8]. The surface finish shall be visually inspected.

For 250 x 250 x 10 mm sections the corresponding square profile test-gauge shall be 226 x 226 mm.

3.2 Inspection of welds

Welded hollow sections intended for cassettes shall be visually inspected for welding defects. Requirements, see 2.1 and 2.2.

3.3 Identification

The steel grade identity shall be ensured. However, no individual marking of the steel sections is required by SKB.

3.4 Mechanical properties

No specific tensile or impact testing (i.e. testing specimens from the current sections or from the lot of which the sections are a part) is required. The manufacturer shall, however, be able to show evidence that sections of the size in question, manufactured under similar conditions, will meet the requirements specified in the applicable standard[9].

4 Inspection and testing of other steel parts

The steel grade identity of other steel parts intended for cassettes shall be ensured in accordance with industry practice. No additional SKB inspection and testing requirements presently apply.

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[8] SKB KTS001F-1

[9] Requirements on specific testing, including sampling, may be added in a later revision of this document.

Technical Specification No KTS022

Profiles for Steel Section Cassette

Revision No 1
Valid from 13 Mar 2003
Prepared by M Westman
Reviewed by L Werme
Approved by C-G Andersson

Docqa reg. No 3425-2572

5 Manufacturer's documentation

5.1 Material certificate

The manufacturer of the sections shall issue a certificate according to EN 10204 2.2 or 3.1.B [10], stating as a minimum:

- the manufacturer's name and address,
- date of issue,
- reference to applicable material/product standard,
- steel grade and execution,
- dimensions,
- for EN 10204 2.2 certificate in addition:
  - typical chemical composition; or
- for EN 10204 3.1.B certificate in addition:
  - original heat or cast number,
  - actual chemical composition.

5.2 Submission of documents and information

The material certificate according to 5.1 shall be sent to the cassette manufacturer for check of compliance with standard and purchase order.

The cassette manufacturer shall, without delay, give complete information to the applicable foundry or directly to SKB on all observations and other circumstances in connection with the production, which may influence the design or properties of the canister components. SKB shall have the right to use this information without any restriction.

5.3 Retention of documentation

QA Co-ordinator Canister Manufacturing Technique, QASK, is responsible for the retention of documentation according to section 5.1, described in a separate procedure [11].

The cassette manufacturer shall retain the documentation according to section 5.1 for (at present) at least 10 years under suitable security. If any records are stored on electronic/magnetic media the readability shall be ensured for this time period.

6 Document control

QASK is responsible for document control, including distribution, of this technical specification [12].

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[10] EN 10204:1995, Metallic materials – Types of inspection documents

[11] SKB Procedure KT1002, Retention of quality documents and records

[12] SKB Procedure KT1001, Establishing and control of SKB procedures and technical specifications

Appendix 8

Quality System – Canister Fabrication. Manual Contents

Inkapslingsteknik –
Kapseltillverkning Flik nr 1 Sida nr 1

Kapitel 1
Rev nr 6
Giltig från 2004-04-02

Översikt
Granskad av
Godkänd av

Docqa reg.nr 3425-2559

Innehållsförteckning

Appendix 9

Quality System – Canister Fabrication. List of procedures

Inkapslingsteknik –
Kapseltillverkning
Sida nr 1 (1)

Rev nr 5
Giltig från 2003-03-13
Granskad av
Godkänd av

Förteckning över Rutiner

Förteckning över Rutiner (Procedures)

Rutin	Rubrik	Rev
KT0501	Requirements for external quality auditing	5
KT0601	Techniques for quality analysis	3
KT0602	Qualification of manufacturing process	3
KT0603	Qualification of supplier/subcontractor (manufacturing)	3
KT0604	Qualification of supplier/subcontractor (inspection and metrological confirmation)	3
KT0605	Qualification process for NDT of canister components	Draft A
KT0701	Final inspection and testing	3
KT0702	Handling, storage, packing and transport of canister components and assembled canisters	3
KT0703	Delivery of canister components and assembled canisters – documentation	3
KT0704	Requirements on 1) quality plan, 2) manufacturing and inspection plan	4
KT0705	Identification of canister components and assembled canisters	4
KT0801	Control of inspection, measuring and test equipment	2
KT0803	Receiving and acceptance inspection	1
KT1001	Establishing and control of SKB procedures and technical specifications	3
KT1002	Retention of quality documents and records	4
KT1003	Handling of documents on canister components and assembled canisters from trial manufacture	4
KT1005	Handling of drawings for canister components and assembled canisters	2
KT1101	Control of nonconformities at SKB	2
KT1102	Request for concession	3
KT1103	Control of nonconformities at supplier	3

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