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DEVELOPMENT OF FORGED STEEL APPLIED TO MAIN BODY OF TYPE B(U) PACKAGE

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ABSTRACT

Mitsubishi Heavy Industries, Ltd. (MHI) has developed MSF-57BG spent fuel transport and storage cask. Newly developed forged steel is applied to body shell and base plate for the cask. The cask material (called LF3-m) was developed based on ASTM A350 LF3 to improve fracture toughness and to provide high strength at elevated temperature. At 150°C LF3-m keeps mechanical strength equivalent to that of A350 Grade LF5 material at room temperature. The material test results using forging of LF3-m as a trial proved that the material is well suited to build the main body for the transport and storage cask.

INTRODUCTION

According to IAEA transport regulation[1)], a package of type B(U) shall be designed considering an ambient temperature from –40°C to +38°C. A ferritic material is brittle at low temperature. Therefore, brittleness must be considered at low temperature as well as strength at high temperature. Furthermore, taking into account the manufacturing process, it is necessary to consider weldability. Therefore, the new material was developed based on A350 Grade LF3[2)] considering these three requirements.
This report describes the summary of the newly developed material, LF3-m.

OUTLINE OF THE DEVELOPED MATERIAL

To demonstrate the structural integrity and containment integrity of the MSF series cask, MHI performed a series of drop tests using a 1/1 scale model cask under the supervision of BAM, competent authority of Germany and it was confirmed that structural and containment integrity could be kept under drop tests defined in IAEA transport regulation. The body shell of the model cask is made of A350 Grade LF5 and its yield strength at room temperature was almost 350MPa as a result of tension test. These drop tests were performed at room temperature but a cask body for operational cask will be heated to approximately 150°C due to heat power of radioactive content. Therefore it was necessary to show that the cask would keep its containment integrity even in the highest service temperature. Therefore, we needed to develop new material to keep mechanical strength at 150°C to be equivalent to that of A350 Grade LF5 at room temperature. Requirements to employ body shell for MSF-casks were shown in Table 1.

Table1 Requirements of new material to body shell for MSF-casks

Items	Requirements
Tensile properties at elevated temperature	YS (0.2% PS) > 350 MPa at 150°C
Dynamic fracture toughness	K_{Id}>55 MPa$\sqrt{m}$ at -40°C
Weldability	$\Delta G < 0$ and $P_{SR} < 0$

Note: ΔG and P_{SR} are known as parameters to estimate sensitivity for weld cracking. These parameters are obtained by the following equations.

$\Delta G = Cr + 3.3Mo + 8.1V - 2\ (\%)$ [4)]

$P_{SR} = Cr + Cu + 2Mo + 10V + 7Nb + 5Ti - 2\ (\%)$ [5)]

ASTM A508 series ferric forged steel, which must have high mechanical strength and fracture toughness, was selected as a candidate. However, its parameters of sensitivity of weld cracking, ΔG and P_{SR}, might be larger than zero and it makes pending issue remain. Therefore, to conform to the requirements shown in Table 1, newly material was developed based on A350 Grade LF3 which has good property for fracture toughness and added small amount alloy elements contributing to increase the mechanical strength with keeping the ΔG and P_{SR} to be lower than zero.

TEST FORGING

To verify properties of LF3-m, an ingot weighting 30 ton of LF3-m was made and applied as test forging.

Specification of the test forging

The test forging was manufactured to verify that LF3-m could be applied to operational casks. All manufacturing processes such as electric furnace melting, ladle refining, ingot making, forging, forming, water quenching and tempering were performed in accordance with estimated process of forgings for operational casks. The shape of forging was simplified to be formed of thick plate of 2000mm x 3000mm x 460mm. Heat treated thickness of 460mm, which was the same as operational cask, was applied to the test so that cooling rate would be the same as that for operational cask. As a result of ladle analysis, the parameters of sensitivity of weld cracking, ΔG and P_{SR}, of test forging were respectively -0.7 and -1.0.

Method of the tests

Basically material tests were performed in accordance with material standard, ASTM A350. As test items, tensile test, Charpy impact test, fracture toughness test and microscopic observation were performed. Test coupons were mainly removed from 1/4T in accordance with the standard and some coupons were additionally removed from surface and1/2T, where T means heat treated thickness. Testing directions were also basically in accordance with the standard but some tests were performed with test coupons taken in other directions to verify influence of forging direction.

RESULTS OF MATERIAL TESTS

The results of the qualification tests are shown below.

Tension test at room temperature

Figure 1 shows the result of tensile test at room temperature. The tension tests were performed at the surface and 1/4T and 1/2T from heat treated surface. It was confirmed that the tensile properties do not depend on testing location. It was also confirmed that the test coupons have enough elongation and reduction to put into practical use.

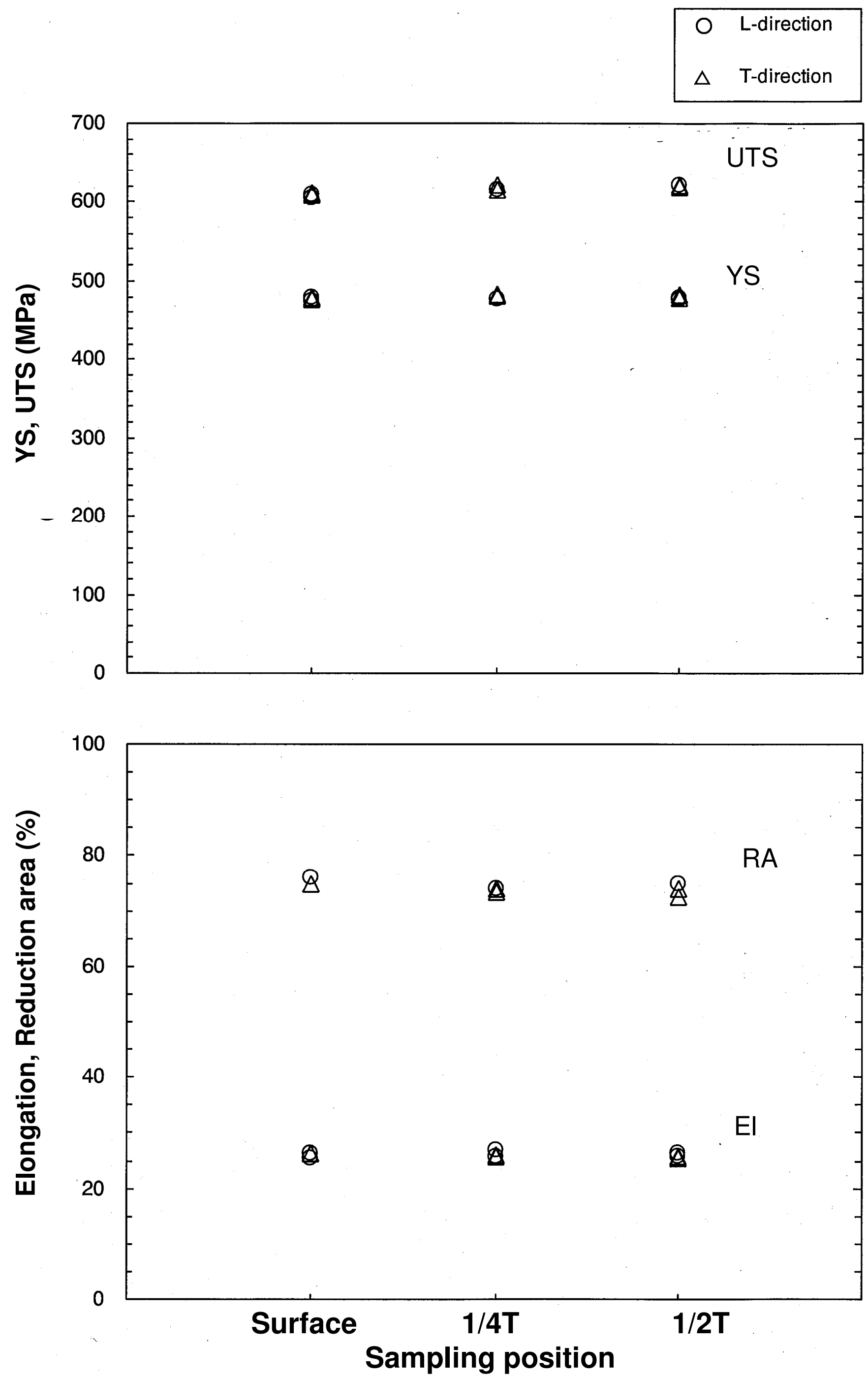


Figure 1. Result of tensile test at room temperature

Tension test at elevated temperature (150°C)

Figure 2 shows the results of tensile test at elevated temperature. The yield strength (0.2% proof strength) at 150°C is greater than 350MPa, which met the required value.

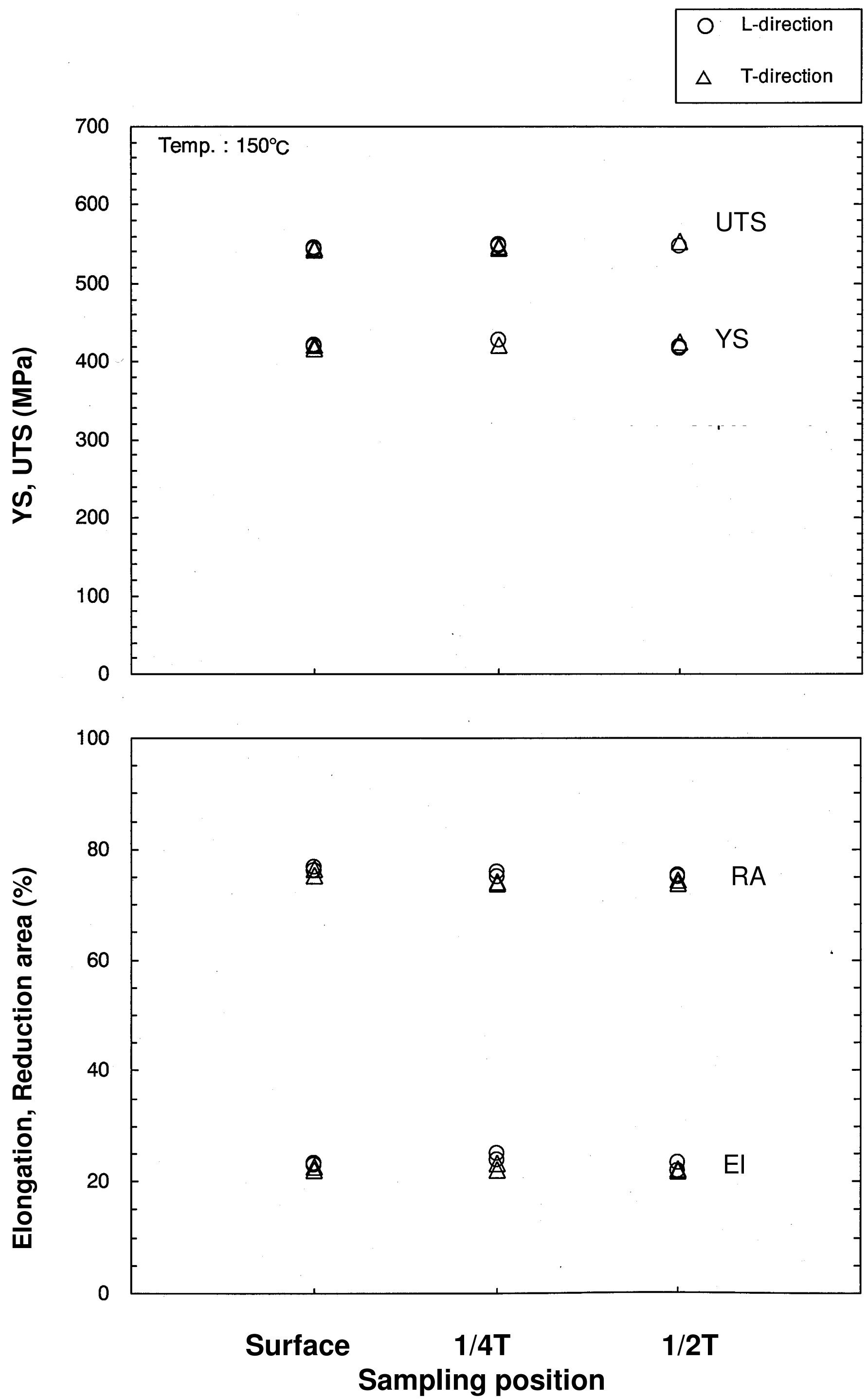


Figure 2. Result of tensile tests at 150°C

Charpy impact test

Figure 3 shows the results of Charpy impact tests. Absorbed energy at -40°C is approximately more than 100J. It was also confirmed that the LF3-m is appropriate to use at low temperature.

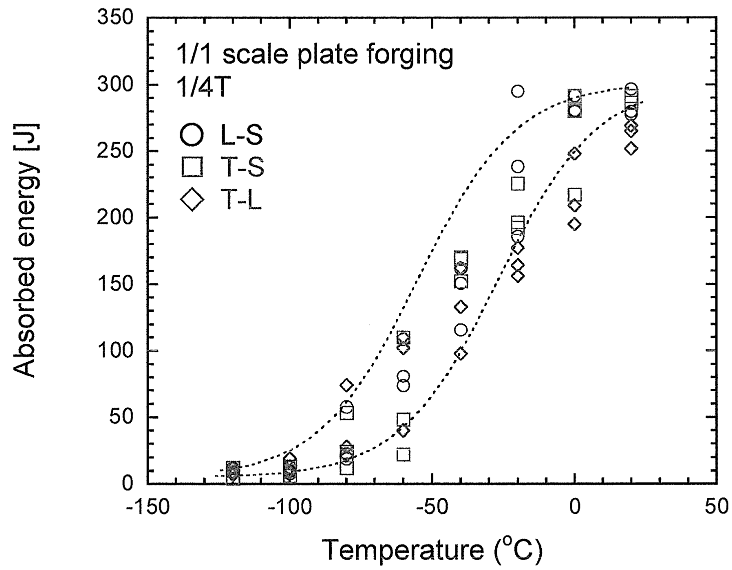


Figure 3. Result of Charpy impact tests

Dynamic fracture toughness

Dynamic fracture toughness was obtained from quasi static fracture toughness test. The test data were processed as the following steps.

Step 1 Quasi static fracture toughness test was performed in accordance with ASTM E1921[6)]

Step2 Reference temperature, T_0, was calculated form test data in accordance with ASTM E1921

Step3 Other index reference temperature, $RT_{T0}(=RT_{NDT})$, was determined in accordance with ASME Code case N-629[7)] and N-631[8)]

Step4 Dynamic fracture toughness, K_{Id}, was obtained by using reference fracture toughness, K_{IR}, curve[9)] in accordance with ASME Code Section III Appendix-G.

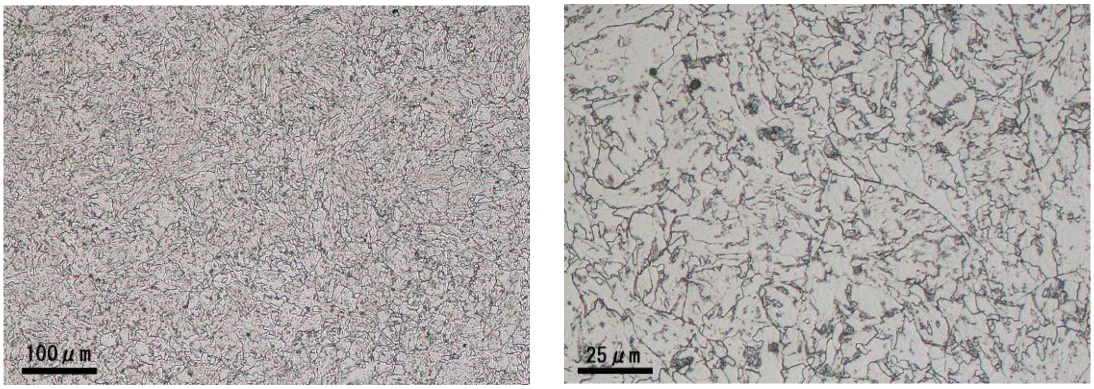
The processing results are summarized below. It was verified that dynamic fracture toughness of the test forging satisfies the required value.

T_0 = - 93(°C)

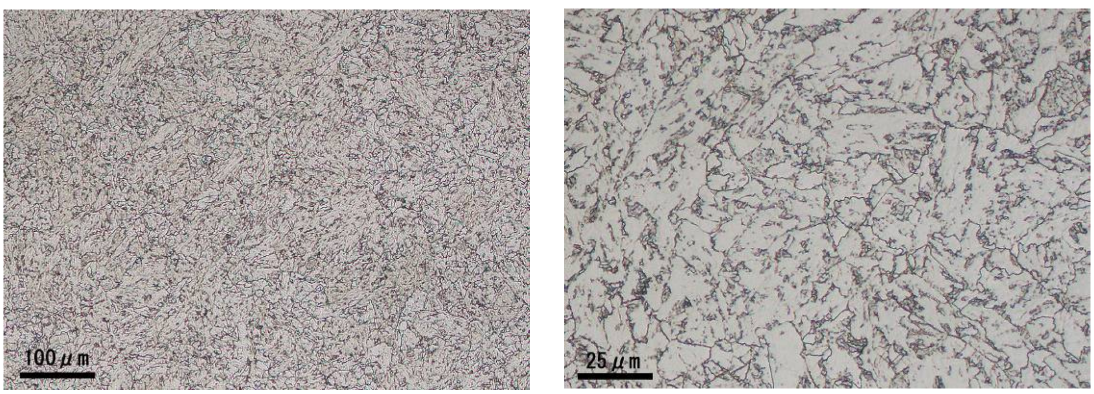
K_{Id} = 62 (MPa$\sqrt{m}$ at - 40°C)

Microscopic observation

Microstructure of LF3-m is shown in Figure 5. Typical bainite structure was observed in more than 20 points of the microscopic photographs of LF3-m. Microstructure in all the points was almost the same, which proved homogeneity of test forgings.



a) Surface



b) 1/2 T

Figure 5. Microstructure of LF3-m

CONCLUSIONS

The new material, LF3-m, was developed to improve tensile strength and fracture toughness with keeping weldability. As a result of material examinations using test forging, it was verified that LF3-m has enough strength and fracture toughness to satisfy the required values. We will apply LF3-m to newly designed casks.

REFERENCES

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8) ASTM A1921-97, “Standard Test Method for Determination of Reference Temperature, To, for Ferritic Steels in the Transition Range”
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