EAN 2014
52nd conference on experimental stress analysis

Experiences Gained During Experimental Verification of Safety of Containers for Transport of Spent Nuclear Fuel

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Keywords: Container, safe operation, experimental analysis.

Abstract. Containers for spent radioactive fuel have to fulfill criterion defined by correspondent regulations. With respect to the long-year operation it was necessary to verify safety during operation. In order to conclude fulfilling of given criterion, on the workplace of authors extensive analyses by computational and experimental methods of mechanics have been accomplished. In the paper are described experiences gained during experimental verification in principle of the same containers.

Introduction

The transport of spent nuclear fuel is accomplished by transport containers with basic dimensions according to Fig. 1.

a) 

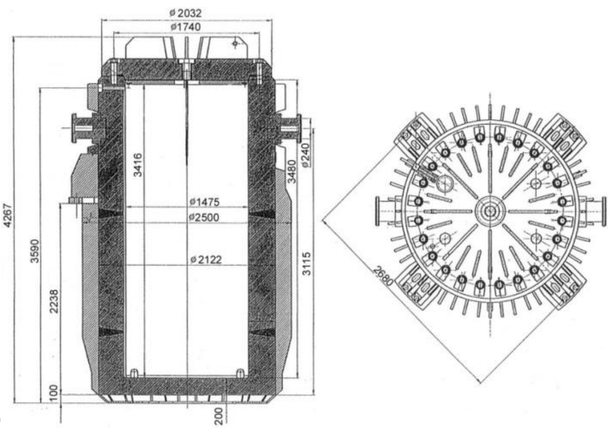
b) 

Fig. 1. Container for transportation of spent radioactive fuel. a) view on container b) basic dimensions of container.

The main parts of containers are:

- body of container made as thick-walled steel vessel with outer ribs,
- lid of container with ribs, the lid is fastened to the body of cask by stud bolts and hermetically sealed,
- two supporting journals for manipulation with container,
- four tighten consoles for joining to special wagon,
- holder, spent fuel cells.

The whole container mass together with transported shipment is approximately 85000 kg.

In the sense of regulation of UJD SR (Nuclear Regulatory Authority of the Slovak Republic) No.57/2006, casks for transport of radioactive materials have to fulfill criterion ensuring their safe operation [1]. On the workplace of authors was realized verification of fulfillment of demands in the sense of above-mentioned regulation for four containers, that were in operation for several decades, by using analytical, numerical as well as experimental methods of mechanics [2,3,4,5,6,7,8].

In the paper are presented experiences gained during experimental verification of safety, in principle identical containers for transport of spent nuclear fuel, oriented to

- determination of residual stresses in casks due to possible overloading during operation, residual stresses from production, radiation, and thermal influences, respectively,
- detection of material lost due to attrition or corrosion,
- identification of possible permanent deformations of container bodies.

Residual Stresses in the Container Bodies

Measurement of residual stresses has been realized on the basis of methodology described in [2]. For the measurement of residual stresses the strain-gage hole-drilling method has been used with system RS 200. With respect to the conditions, it was necessary to use strain-gages RY 21 with the outputs soldered directly during their production in factory. It lead to using of American measurement system RS 200 although its architecture do not allow hole-drilling without pedestal of hole-drilling unit. Further reason for its application was possibility to use smaller tripod with better fixation to the container.

The methodology for determination of residual stresses has been elaborated according to standard ASTM E 837-08 and TECH NOTE TN 503-6 [9,10,11]. Overall view to the positioning of sensors on container bodies I, II, III, IV is given in Fig. 2. Locations 1, 2 and 3 for application of strain-gages have been chosen approximately the same for all containers.

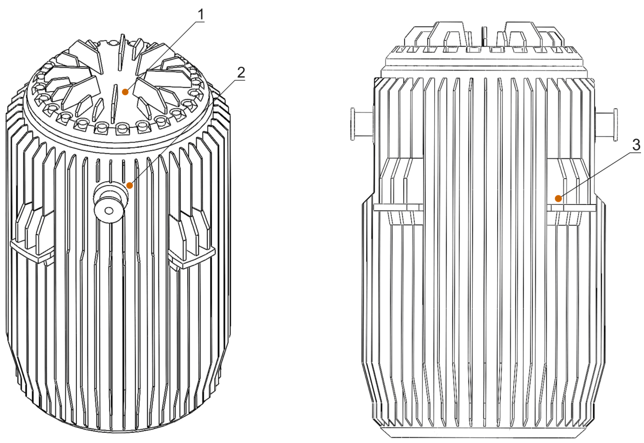
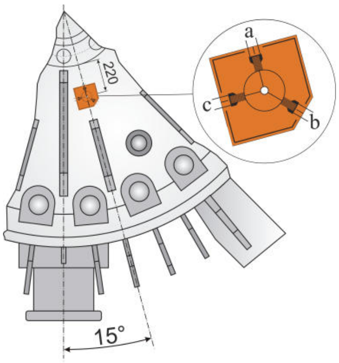
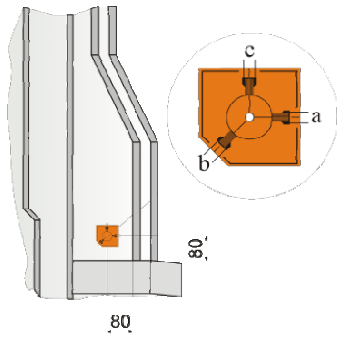


Fig. 2. Overall view to positioning of strain-gages on container bodies I, II, III, IV.

The locations of strain-gages allowed to register the highest level of residual stresses during operation, manipulation and production. At the same time they ensure good availability to applied measurement system RS 200. For the measurement were used strain-gages RY21-3/120 with electric resistance 120 Ω (self-compensating). The strain-gages have been applied by glue X60 and isolated by silicone protective coat SG-250. The position of strain-gages on container has been determined in locations of maximum stresses computed by analytical and numerical methods of elasticity theory. Diameter of drilled holes were 3.2 mm, depth of the hole 5 mm. The hole-drilling was realized in ten steps by 0.5 mm from 0.5 mm to 5.0 mm. The radii of strain-gage rosettes were 5.15 mm. Fig. 3 shows localization of strain-gages for the hole-drilling method on container bodies I, II, III, IV.

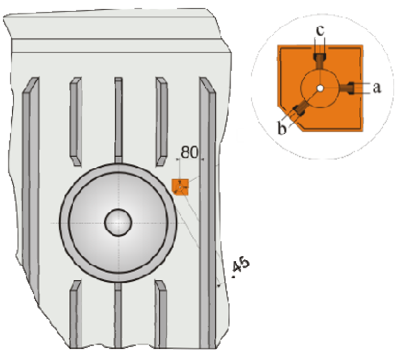


measurement location 1



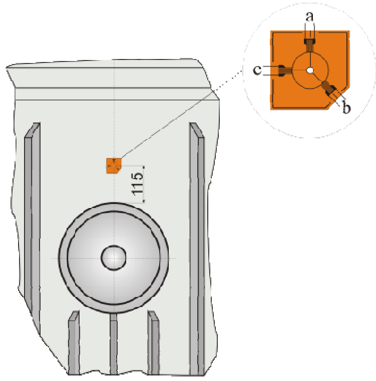
measurement location 3

a)



measurement location 2

b)



measurement location 2

c)

Fig. 3. Localization of strain-gages for the hole-drilling method on container bodies I, II, III, IV. a) location of strain-gages on the lid and rib of all containers, b) location of strain-gage near pin of container I, III, c) location of strain-gage near pin of container II, IV.

In Fig. 4a is presented process of hole-drilling on container in measurement location 1. In Fig. 4b is given a view to strain-gage in location 2 after removing of milling machine. In Fig. 4c is a detail of strain-gage in location 3.

Fig. 4. View to individual measurement locations, a) drilling in location 1, b) hole-drilling equipment at location 2 after removing milling machine, c) strain-gage after drilling, location 3.

In Table 1 are given magnitudes of principal residual stresses and their directions in measurement locations 1, 2 and 3 determined according to standard ASTM E 837-08 for uniform stress distribution.

Table 1. Magnitudes of principal residual stresses according to standard ASTM E837-08.

Location of measurement	Container	σ_{max} [MPa]	σ_{min} [MPa]	φ [°]
1	I	4.82	-13.70	47.46
	II	30.47	15.77	72.33
	III	81.76	67.22	-51.48
	IV	0.43	-20.06	-89.75
2	I	57.00	23.94	-77.86
	II	-3.75	-20.28	5.44
	III	73.44	46.20	-57.39
	IV	-48.19	-60.44	-1.74
3	I	33.54	-26.83	6.15
	II	16.98	-9.13	-33.46
	III	40.20	29.49	-2.49
	IV	-1.53	-21.80	52.14

* φ - deviation angle of stress σ_{max} with respect to the grid axis *a*, positive if counter-clockwise

Determination of Material loss and Identification of Permanent Plastic Deformations of Container Bodies

Measurements of thicknesses of lid, body shell and ribs have been accomplished in locations 1, 2, 3 of containers (Fig.1) by ultrasound measurement system TG-400 with measurement accuracy 0.01 mm. Direct ultrasound sonde NTD SYSTEMS C11 with frequency 5 MHz and measurement scale from 1.6 mm to 508 mm has been used for the measurement. In order to ensure appropriate acoustic bonding between measured surface and ultrasound sonde, bounding means ULTRAGEL II® has been used.

In every measurement location (Fig. 1) five measurements of thickness have been carried out. Average magnitudes of measured thicknesses in locations 1, 2 a 3 are given in Table 2.

Table 2. Average thicknesses measured in individual locations of measurements.

Container No.	Average thickness [mm]		
	1 - lid	2 - wall	3 – rib
I	234,96	326,52	30,23
II	237,84	331,46	29,91
III	234,17	327,70	29,93
IV	237,123	330,98	29,82

Nominal thicknesses in individual locations of containers according to production documents are - lid thickness 235 mm, shell thickness 320 mm, rib thickness 30 mm.

Local plastic deformations were investigated at the first stage by visual inspection. Possible plastic deformations were identified also on the basis of measurement of geometrical parameters by contactless geodetic methods presented in [4].

On the basis of visual inspections of containers I, II, III, IV it was found out that plastic deformations exceed order of mm are only on ribs of container I under pin. From character of plastic deformations is apparent that these deformations could be caused by drop of crane hook during its positioning to pin of container or during manipulation with container. In Fig. 5a is container positioned in location where the measurements of plastic deformations were accomplished. In Fig. 5b is a view to measurement of plastic deformation.

a)  b) 

Fig. 5. a) Container on the location for measurement of plastic deformations, b) Measurement of rib plastic deformation.

Plastic deformations on one container reached magnitudes 5 to 6 mm. Because these deformations are on ribs that ensure cooling, influence of plastic deformations in locations of ribs to strength and stiffness properties of container can be neglected.

The positions of more than 4 millions points on the surface of container have been determined by contactless geodetic method. The measurement concludes that no plastic deformations occur on the lid and cylindrical part of container [5,6].

Conclusion

In the frame of assessment of safe operation of containers (of the same design) for transport of radioactive fuel the following measurements were carried out on four containers: experimental measurement of residual stresses, loss of material due to attrition or corrosion as well as measurement of permanent plastic deformation of containers.

On the basis of gained results can be stated the following:

- Magnitudes of residual stresses determined according to standard ASTM E 837-08 (Table 1) do not pose risk for safe operation, because during vanishing loading occurring during operation of container there is no significant decreasing of critical stress amplitude in comparison to fatigue limit during symmetric loading cycle. Furthermore, number of loading cycles due to internal pressure in container is relatively low and it can be considered as quasistatic, not as fatigue strength. Mechanical properties of cylindrical part of container as well as lid that are predominant for assessment of safe operation clearly define withstand capability and from computed as well as measured values of stresses is apparent that for the levels of residual stresses determined by these methods the lifetime of container is guaranteed.
- From the measured values of principal residual stresses determined in locations on container III is apparent that these values are bigger than those on other measured containers. Very important is fact that the stresses have character of tensile stresses in all locations of measurements and because they are very small for operational loading, and transport and also number of working cycles is small, their influence to lifetime can be neglected.

- Material loss due to or corrosion can be determined from differences computed from nominal thicknesses at the beginning of container operation and those measured and written in Table 2. Because the thicknesses from the time of beginning of container operation are unknown, the data from documentation has been used (lid thickness 235 mm, shell thickness 320 mm, rib thickness 30 mm). As results from Table 2, maximum average loss measured on a lid was 0.83 mm (0,35%) and on the rib 0.18 mm (0.60 %). The thicknesses measured on the container shell were bigger than nominal values from documentation.
- Visual inspection as well as application of contactless geodetic method for sensing of container surfaces concludes that the container bodies do not have plastic deformations that could threaten their safe operation.

Though there were detected some differences by application of presented test treatments on four containers (particularly in magnitudes of residual stresses), on the basis of experimentally determined methods of geometric parameters, residual stresses, material loss as well as visual inspection and identification of plastic deformations can be stated that the verified containers have sufficient residual lifespan and they can be used in prescribed operation conditions without any restrictions.

Acknowledgement

This article was created with support of grant projects VEGA 1/0937/12 Development of unconventional experimental methods for mechanic and mechatronic systems and VEGA 1/0393/14 Analysis of causes of mechanical systems failures by the quantification of strains and stress fields.

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