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PIC-CONTAINER FOR CONTAINMENT AND DISPOSAL OF LOW AND INTERMEDIATE LEVEL RADIOACTIVE WASTES

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Steel fiber reinforced polymer-impregnated concrete (SFPIC) has been investigated for low and intermediate level radioactive waste containers. The present study has been carried out by the following stages. A) Preliminary evaluation: 60 L size container for cold and hot tests. B) Evaluation of size effect: 200 L size container for cold tests.

The 60 L and 200 L containers were designed as pressure-container (without equalizer) for 500 kg/cm^2 and 700 kg/cm^2. Polymerization of impregnated methylmethacrylate monomer for stage-A and B were performed by ^{60}Co-γ ray radiation and thermal catalytic polymerization, respectively.

Under the loading of 500 kg/cm^2 and 700 kg/cm^2-outside hydraulic pressure, these containers were kept in their good condition. The observed maximum strains were about 1380×10^{-6} and 3950×10^{-6} at the outside central position of container body for circumferential direction of the 60 L and 200 L container, respectively. An accelerated leaching test was performed by charging the concentrate of the liquid radioactive waste from JMTR in JAERI into the container. Although they were immersed in deionized water for 400 days, nuclides were not leached from the container. From results of various tests, it was evaluated that the SFPIC-container was suitable for containment and disposal of low and intermediate level radioactive wastes. There was not any great difference between the two size containers for the physical and chemical properties except in their preparation process.

Keywords: SFPIC, PIC, Plain Concrete, Low and Intermediate, Radioactive Waste, Disposal, Container, Containment, Outside Hydraulic Pressure, Drop Impact, Leaching, Durability, Corrosion, Stress -Strain, Sea Water, Fire.

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** Chichibu Cement Co. Ltd.

低・中レベル放射性廃棄物の処理・処分用ＰＩＣ容器

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（１９８１年2月4日受理）

低・中レベル放射性廃棄物の処理処分容器として鋼繊維補強ポリマー含浸コンクリートを用いて研究してきた。本報告は次の２段階で実施した結果をまとめた速報である。(1)　６０ℓ（２００ℓドラム缶の2/3寸法モデル）容器を用いたコールドおよびホット試験による予備評価，(2)　２００ℓ（実寸法）容器を用いたコールド試験による容器の寸法効果。

６０ℓ容器と２００ℓ容器はそれぞれ５００kg／cm^{2}と７００kg／cm^{2}の耐圧容器として設計した。(1)，(2)段階の含浸したメタクリル酸メチルモノマーは，各々^{60}Co－γ線と熱触媒法により重合硬化させた。

５００kg／cm^{2}と７００kg／cm^{2}の外水圧力の載荷によって，ＰＩＣ容器は良好な状態を保持し，実測された最大ひずみはそれぞれ６０ℓ容器と２００ℓ容器の外側胴中央部円周方向でおよそ1380×10^{-6}と3950×10^{-6}を示した。ＲＩの促進浸出試験を原研大洗研の材料試験炉から排出した濃縮廃液を容器中に直接入れて実施した。この容器を４００日間イオン交換水中に浸漬したが，放射性核種の浸出は認められなかった。その他の各種試験結果を含めて，鋼繊維補強ポリマー含浸コンクリート容器は低・中レベル放射性廃棄物の処理処分用に適していると評価された。

また，２種類の容器について検討した結果，容器の製造工程における多少の相異を除いて物理的，化学的性質に大きな差はなかった。

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1. INTRODUCTION

In recent years, low and intermediate level radioactive waste generated at nuclear power plants and other atomic energy facilities has been increasing and it is, therefore, an urgent problem to establish a safe disposal and containment system for radioactive waste. The Japanese government will confirm safety and establish sea dumping and ground burial techniques on its own responsibility with the cooperation of the agencies concerned both at home and abroad. For example, "the guideline for sea dumping packages*" is indicated by IAEA (1). It is also said that the container for ground burial is necessary to have a long-term durability over 50 years.

Thus a container for disposal and containment of radioactive waste requires that it must have complete impermeability to radioactive materials and durability under the various conditions for management and it must be resistant to corrosion, resistant to impact and resistant to fire.

Research and development of polymer-impregnated concrete abbreviated as PIC was performed by M. Steinberg, J.T. Dikeou et al in the USA (2). PIC has heigh strength, excellent impermeablity excellent durability and so on. Therefore, we have been examined an application on the PIC-container for radioactive waste since 1973 year. Also, PIC application to the cement solidification of radioactive waste is reported by A. Donato (3) and P. Colombo et al (4).

The PIC-container was designed as a pressure-resistance container without pressure equalizer. However, it was clear that defects of PIC-container were short of impact strength and fire-resistance. We have carried out the fundamental studies on improvement of the defects with fibers reinforced PIC (5), (6), (7). Consequently, the requirements for such the container have been satisfied by newly appling steel fiber reinforced PIC abbribiated as SFPIC.

The present study has been carried out by the following stages. A) Preliminary evaluation is a 60 L size (a 2/3 size model of 200 L drum) container for cold and hot tests. B) Evaluation of size effect is a 200 L size (a full size) container for cold tests.

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* ; It is packaged solid or solidified radioactive waste in a container.

2. METHOD

The design and preparation of containers and the cross section of PIC-containers are shown in Table 1 and Fig.1, respectively. Evaluation tests were mainly carried out by 5 items and their methods are shown in Table 2.

3. RESULTS AND DISCUSSION

3.1 Resistance to Outside Hydraulic Pressure

A stress-calculation for 60 L size PIC-container under 500 kg/cm^2-outside hydraulic pressure loading was carried out by a finite element method. The lines of equivalent stress are illustrated in Fig.2. The maximum compressive stress of 1500 kg/cm^2 was expected at inside central position in circumferential direction. Therefore, if the container is imploded by high hydraulic pressure, the implosion will be occured at this position.

The comparison of the stress-strain curves and the deformation figures calculated from the observed strain for various containers under outside hydraulic pressure loading are shown in Fig.3 and Fig.4, respectively.

At 425 kg/cm^2, the maximum strain of plain concrete-container of 60 L was about 6050×10^{-6} and its maximum average deformation to radius direction reached about 0.50 mm, and immediately after it was imploded at 427 kg/cm^2. The imploded position was approximately central part of container body.

The SFPIC and PIC-containers of 60 L did not loose integrity by the loading of 500 kg/cm^2 - 3 min. The increased weight of SFPIC and PIC-containers were 1.6 kg and 0.5 kg, respectively. Both water absorption of the containers were below 0.5 %. The maximum strains at inside and outside central part of the SFPIC-container were about 2880×10^{-6} and 1380×10^{-6}, and those of the PIC-container were 3980×10^{-6} and 1720×10^{-6}, respectively. The deformation was estimated from the each strain as the each part of container was equally deformed by the pressure loading. Although the average in deformation to radius direction reached about 0.33 mm and 0.34 mm, these deformation were below 0.50 mm of implosion limit. Therefore, the integrity of the containers is reasonable.

The SFPIC-container of 200 L did not loose integrity by the loading

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The SFPIC-container of 200 L did not loose integrity by the loading of 700 kg/cm^2-1 min. The increased weight of container after test was 1.6 kg and its water absorption was 0.2 %. The maximum strain at outside central part was about 3950×10^{-6} and the average deformation to radius direction reached about 0.92 mm. This value was close to 1.10 mm of the implosion limit which was measured in other container. Therefore, it may be designed by considering a safety rate in the actual use.

From these results, it is clear that a pressure container made of SFPIC or PIC can withstand outside hydraulic pressure of 700 kg/cm^2 corresponding to 7000 m depths in the sea floor, which is more deep than the depth of the expected dumping site in Japan.

3.2 Resistance to Drop Impact

The tests were mainly performed from horizontal position which gave the severest drop impact. The results of drop impact test for 60 L container are illustrated in Table 3. Here, dropping from 0.6 m height corresponds to the dropping speed of the container in the sea and 1.2 m height corresponds to criterion for transport of A-type container indicated by IAEA. 2.0 m height considers dropping accident under the transport.

As regards the plain concrete and PIC-container, cracks were observed on the container body by the dropping from 0.6 m and 1.2 m height. The SFPIC-container kept integrity by the dropping from 0.6 m height. By the dropping from 1.2 m height, a few hairline cracks occured in resinous adhesive but no change in the container body. And this container equipped with simple shock absorbers could withstand the impact of dropping from 2.0 m height.

The dropping behavior of the container was observed by high speed camera. The G value of deceleration or acceleration was measured at three positions of container with acceleration sensors. Fig.5 shows a typical behavior and deceleration-acceleration waves for container at landing in drop impact.

Acceleration sensor gave G value of minus or plus and they were defined as acceleration or deceleration, respectively. An evaluation of drop impact was discussed by the deceleration value. In general, the G alue of second landing was heigher than that of first landing.

The variation of maximum G value of deceleration with drop impact is shown in Fig.6. The maximum G values by dropping from 0.6 m and 1.2 m height were approximately 1000 G and 1400 G, respectively. The maximum

G values were extremely lowered by the using of two rubber belts. As a result, it is clear that the SFPIC-container can withstand to impact of 1000 G and can almost withstand up to 1400 G. Therefore, if the maximum G value generated with drop impact is lower than the G value which may be destructed or it is lowered than the limit value by using some shock absorbers, the containers keep integrity.

Also, when the SFPIC-containers of 200 L were dropped from 1.2 m height, a few hairline cracks occured on the surface of container but no change in the interior of container. The damage of the cement solidified-container was lower than that of the empty container.

From these results, it is clear that the SFPIC-container is not disintegrated by the dropping from 1.2 m height corresponding to IAEA criterion and the size effect of container is not great.

3.3 Resistance to Leaching of Radioactive Materials

The guideline for sea dumping(1) prevents disposal of the liquid radioactive waste which is not solidified by some methods. In the present study, an accelerated leaching test was performed by charging the concentrate of the liquid radioactive waste into the PIC-containers. They were immersed in deionized water for 400 days. Since the radioactivity of the sampling water was under the detectable limit; 2.7×10^{-8} μCi/ml, nuclides were not leached from the containers.

Therefore, the container made of PIC is suitable for the disposal and containment of radioactive waste.

3.4 Resistance to Sea Water

Although iron rust was observed around the cap nuts of plain concrete-containers, the change in appearance of the PIC-containers was not observed by the immersion in sea water for 400 days.

3.5 Resistance to Fire

A preliminary open fire test was performed by using plain concrete, PIC and SFPIC-caps. Many cracks on the surface of plain concrete and PIC-caps were observed and they were disintegrated around the reinforcing bars by striking them with a hammer. However, the SFPIC-cap was not disintegrated by striking.

Fig.7 shows SFPIC-container of 60 L exposured in flame. Kerosene of 50 L was burnt for 30 min, and then it was quenched rapidly by a fire pump.

Although the impregnated polymer and adhesive were baked or burned and some hairline cracks occured on the surface of the container, the container itself was not disintegrated by striking them with a hammer and only the surface of the container suffered partial stripping. Furthermore, after the test this container was moved easily without any damage by a forklift.

Fig.8 shows the change of temperature at individual positions for a cement solidified 200 L SFPIC-container on closed fire test in furnace. The container was exposured at 800 °C for 30 min in a flame which burnt propane gas. The maximum temperature at the inside wall and solidification itself in container were approximately 100 °C which was lower than the expected temperature. Many hairline cracks and a few cracks were observed on the container surface but no change in the interior of container. The container was also moved easily without any damage by a forklift.

In general, when a concrete container is exposed to high temperature, internall stress develops(7) because of the volatization of gas and the difference in cofficient of thermal expansion between the materials of which it is constructed, thus causing cracks. The fire-resistance of the SFPIC-container is much higher. The improved reason may be that the growth of microcracks is prevented by the reinforced steel fibers in the concrete. For the reasons stated above, this container is also practicable for use as a storage container used on land.

CONCLUSION

It is well known that concrete structures have long-term durability, however, the concrete structures are apt to deteriorate by freezing - thawing action, chemical attack or in special circumstances.

The PIC-containers indicated excellent resistance to outside hydraulic pressure, impermeability to water, resistance to leaching of radioactive materials and resistance to sea water because of the many cavities in concrete are filled with non-corrosive polymer. Furthermore, the defects of PIC-container such as resistance to fire, high temperature and drop impact were improved by reinforcing of steel fibers. It was also confirmed that there was not any great difference between the two size containers for physical and chemical properties.

Thus the SFPIC-container for low and intermediate level radioactive waste may be available to a pressure container for a sea dumping and a

long-term storage container for on land or ground burial. Consequently, it should be expected that the package of SFPIC-container can remarkably decrease the diffusion of radioactive waste compared with the package solidified in the conventional steel drum.

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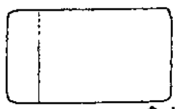
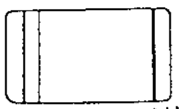
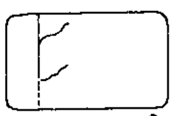
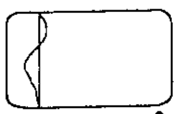
Table 1 Design and preparation of containers

Items	60 L container	200 L container
a) Outer size of container	60 L size (2/3 scale model of 200 L drum)	200 L drum size
b) Type of container	A pressure container (without pressure equalizer)	A pressure container
c) Strength of pressure - resistance	500 kg/cm^2 (corresponding to 5000 m depths in sea)	700 kg/cm^2 (corresponding to 7000 m depths in sea)
d) Adhesion of cap and container	Epoxy resin and tightening with 4 bolts	Epoxy resin and tightening with 8 bolts
e) Material	PIC, Plain concrete, SFPIC	SFPIC
f) Polymerization method	Radiation method: ^{60}Co-γ ray, 8 Mrad	Thermal catalitic polymerization, 95 °C-2h
g) Impregnant	Methylmethacrylate monomer + polystyrene (5wt%)	Methylmethacrylate monomer, Catalyst: Azobisisobutyronitrile (1.5wt%)
h) Solidification	Empty (No solidification)	Cement solidification of simulated radioactive waste

Table 3 Results of drop impact test for 60L container.

Materials	Drop height (m)		
	0.6	1.2	2.0
SFPIC	 (Integrity)		 (Integrity)
PIC			————
Plain concrete			————

Note

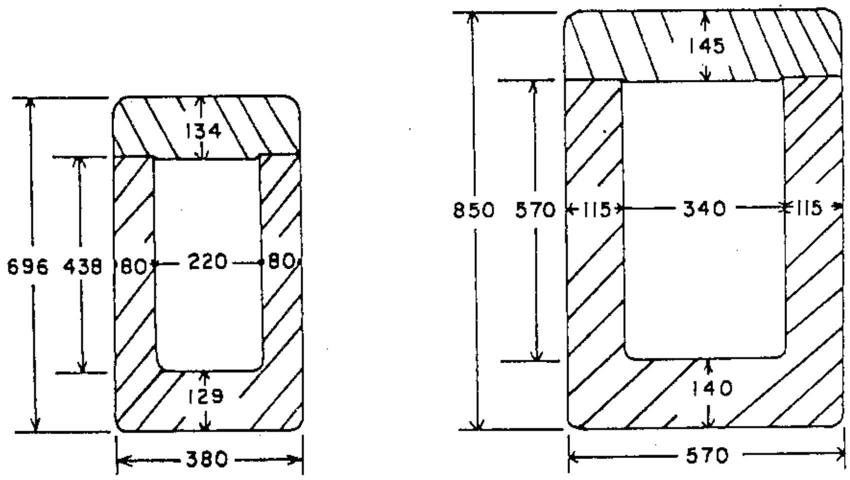
a). ↑Shows the first landing part.

b). Two rubber belts of 17mm$^{\phi}$ were used as shock absober.

Table 2 Methods of evaluation test

Items	60 L container	200 L container
a) Resistance to outside hydraulic pressure	500 kg/cm^2 - 3 min	700 kg/cm^2 - 1 min
b) Resistance to drop impact	Containers were dropped on concrete plate of 25 cm thick putted on iron base. Dropping height was 0.6 m, 1.2 m and 2.0 m.	Containers were dropped on iron plate of 25 mm thick putted on concrete base. Dropping height was 1.2 m
c) Resistance to leaching of radio-active materials	Concentrate* of liquid radioactive wate from JMTR in JAERI was charged in container and immersed in deionized water for 400 days after sealing.	———
d) Resistance to sea water	Immersion of container in sea water for 400 days.	———
e) Resistance to fire	Open fire test in outdoor. Specimen was kept standing in a 50 L - kerosene flame for 30 min.	Closed fire test in furnace. Specimen was kept standing in propane gas flame at 800 °C for 30 min.

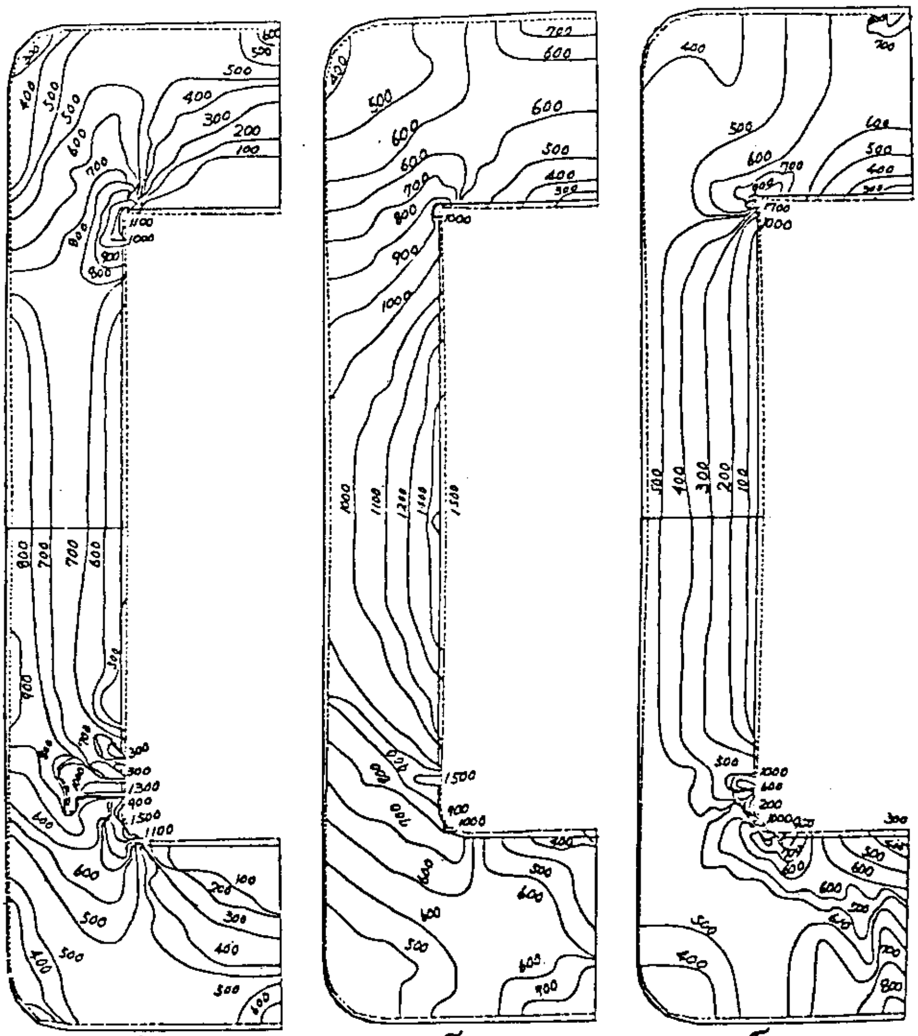
* ; Physical properties of concentrate were the following, PH = 10.6, s.g. = 1.16, solid content = 19.8%, Activity; gross(β) = 1.2×10^{-2} μCi/ml, gross(γ) = 1.1×10^{-2} μCi/ml, Main nuclide;. ^{60}Co = 2.6×10^{-3} μCi/ml, ^{137}Cs = 5.6×10^{-3} μCi/ml.



A) 60L Size
Internal volume ≑ 16L
Weight ≑ 150 kg

B) 200L Size
Internal volume ≑ 51L
Weight ≑ 410kg

Fig.1 Cross section of containers



σ_z (axial direction)

σ_θ (circumferential direction)

σ_r (radial direction)

Fig.2 Lines for equivalent stress calculated as 500 kg/cm² — outside hydraulic pressure using finite element method for 60L size container.

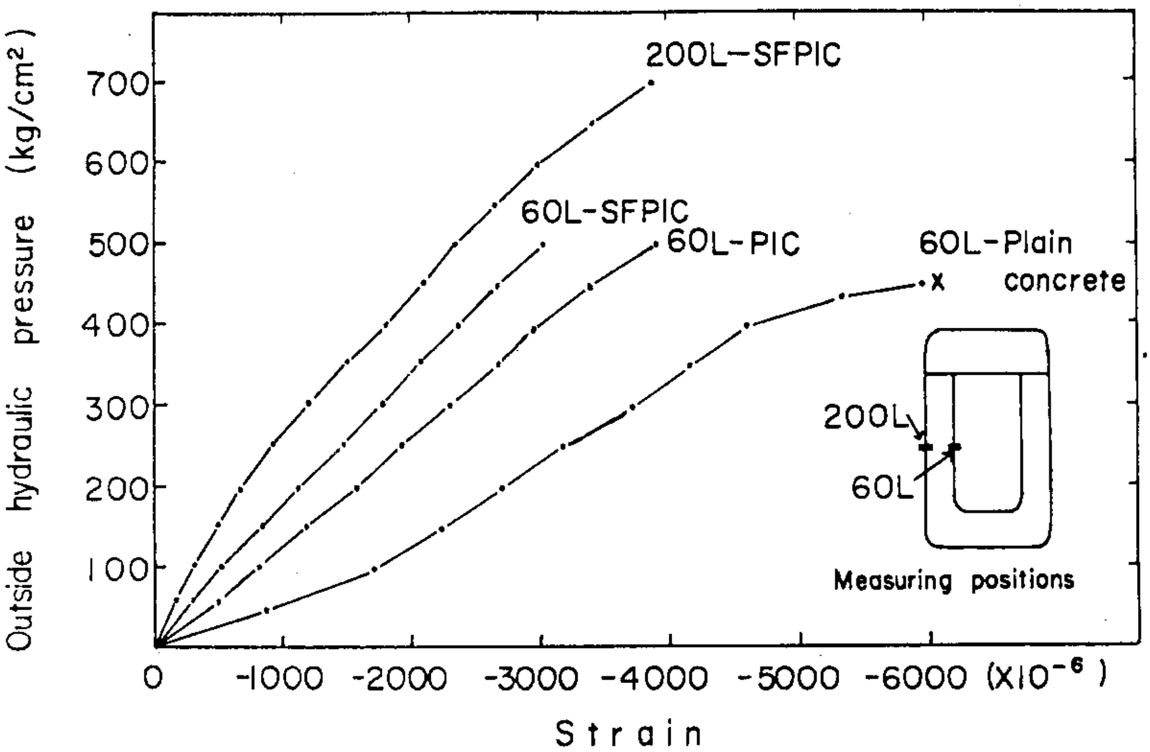


Fig.3 Comparison of stress-strain curves for various containers under outside hydraulic pressure loading.

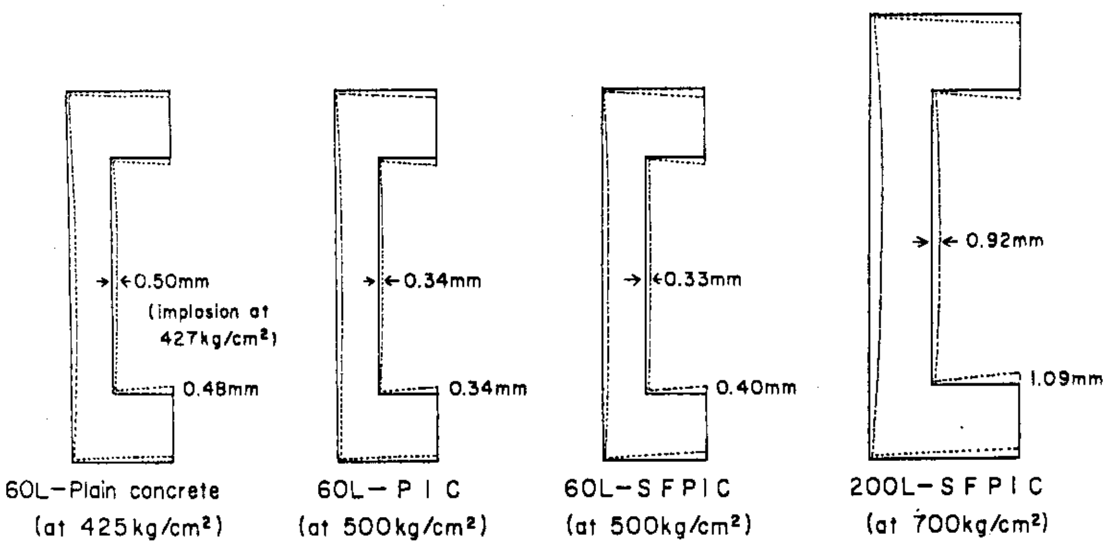


Fig.4 Comparison of deformation figures for various containers under outside hydraulic pressure loading.

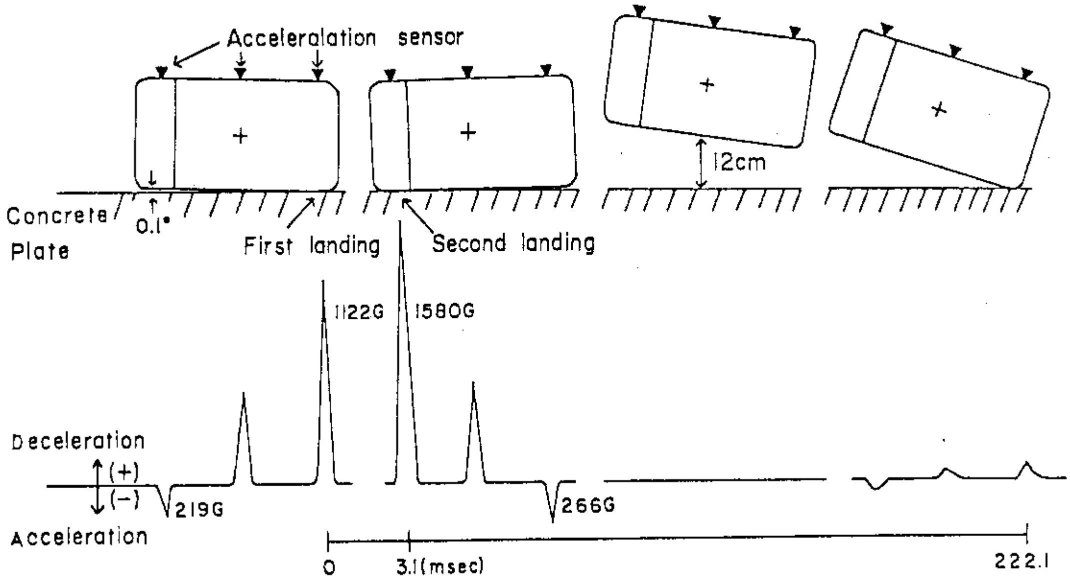


Fig5 Typical behavior and deceleration—acceleration waves for container at landing in drop impact. This figure shows a example of 60L SFPIC–container dropped from 1.2m height.

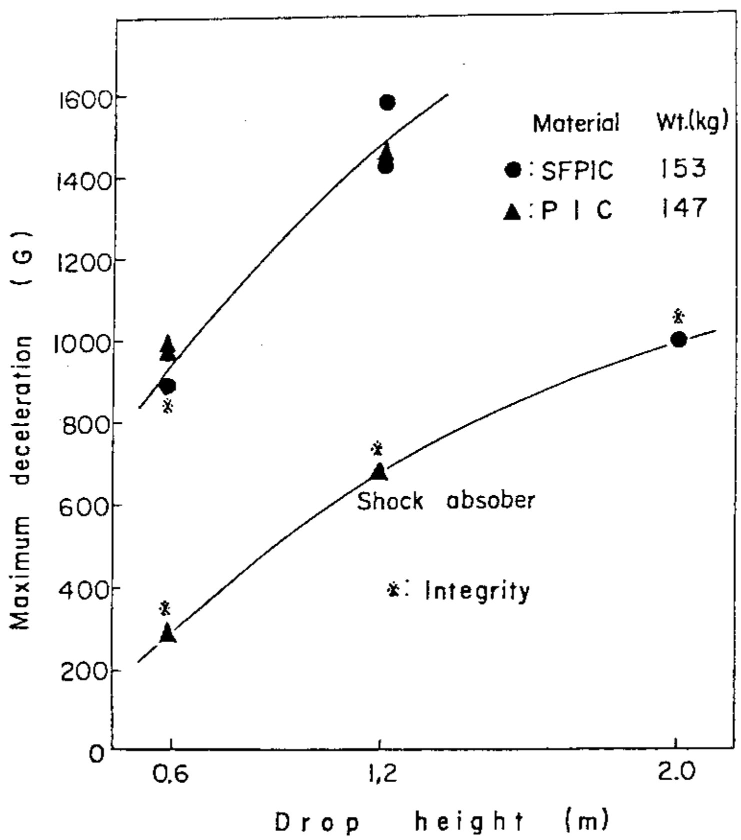


Fig.6 Variation of maximum deceleration with drop height.

Fig.7 Open fire test. 60 L SFPIC-container was exposed to a kerosene flame for 30 min.

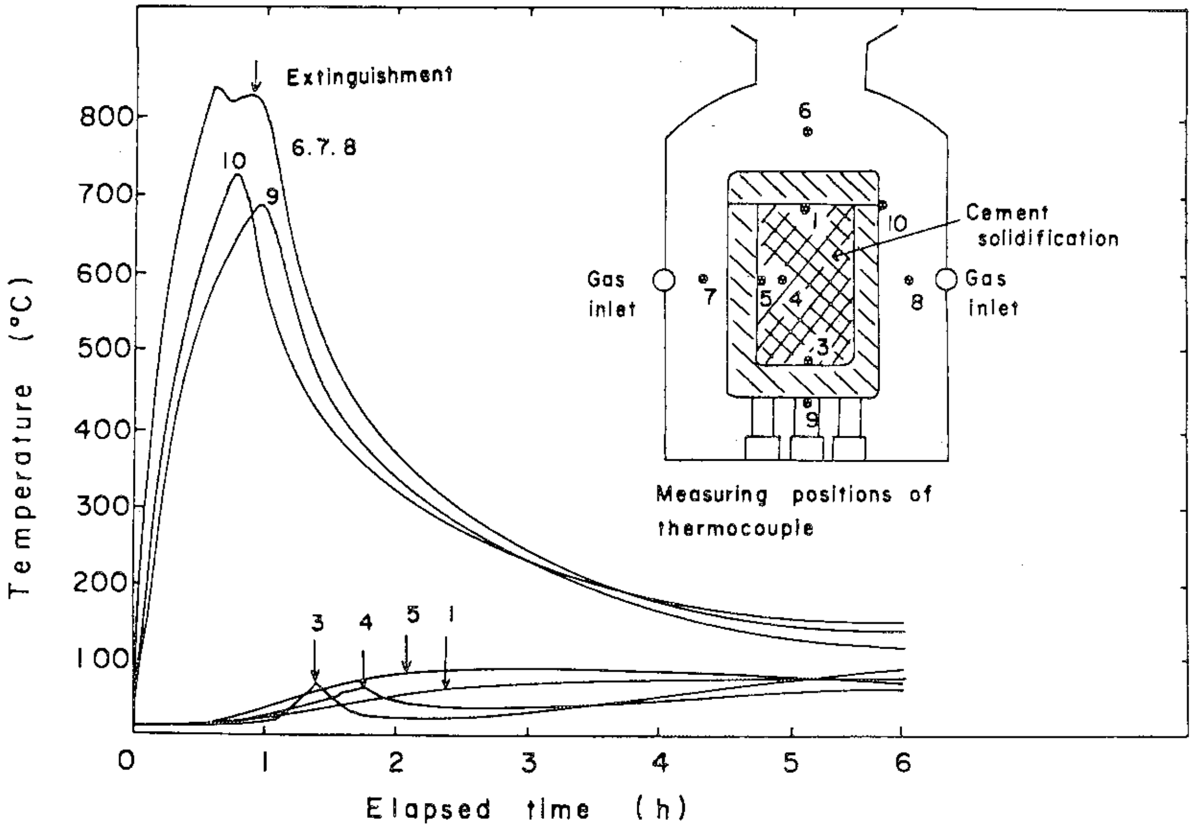


Fig.8 Change of temperature at individual positions for a cement solidified 200L SFPIC-container on closed fire test in furnace.