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Evaluation of metal cutting technologies for decommissioning of nuclear power plants

Ga-Ram Lee [a,b], Byung-Ju Lim [a] and Chang-Dae Park [a,b*]
[a] *Department of Plant Convergence, Korea Institute of Machinery & Materials, 34103Korea*
[b] *Plant System and Machinery., University of Science &Technology, 34113 Korea*
[*] *Corresponding author: parkcdae@kimm.re.kr*

1. Introduction

Currently, there are about 600 nuclear power plants (NPPs) in the world, 165 of them have been permanently suspended and 19 have been dismantled [1]. In Republic of Korea, if the lifespan of the NPPs is not extended, 20 NPPs will be shut down by 2040. At present, the Korea Atomic Energy Research Institute (KAERI) has dismantling experiences for research reactor from 1997 to 2005 and uranium conversion facilities from 2001 to 2011 [2]. As the NPPs are aging globally, the decommissioning market of nuclear facilities will continuously grow and International Atomic Energy Agency (IAEA) estimates it will reach about 1,000 billion dollars by 2050 [3].

The decommissioning of a NPP consists of five stages: preparations of decommissioning, decontamination, dismantling, waste disposal and environmental restoration. The dismantling stage involves removal of components and structures, packaging of wastes, and transport of packages. In the dismantling process, selection of the most effective segmenting technologies, which are low cost and low amount of waste with fast cutting speed, is important for dismantling planning. There are various metal cutting techniques applicable to nuclear decommissioning such as thermal cutting, electrical cutting, and mechanical cutting. Since the objects and conditions in dismantling of the NPPs are very diverse, it is necessary to select the effective cutting techniques considering important factors such as cutting speed, cutting thickness, material, cost, and amount of secondary waste generation. However, previous studies have presented cutting performance for only a part of the consideration factors according to some cutting technologies and do not provide a systematic methodology based on cutting performance data for selecting the optimal cutting technique [4-13].

Therefore, in the dismantling of the NPPs, to select the effective cutting technique considering the cutting target object and conditions, it is required to integrate and organize the cutting performance data with various factors, and then to establish a systematic process with both quantitative and qualitative evaluations.

In this study, we have selected the significant factors for selecting the optimal cutting technique and integrated and tabulated the quantitative / qualitative data from a number of research papers and reports.

2. Metal cutting technologies

2.1 Mechanical cutting technologies

Mechanical cutting techniques include shears, nibblers, saws, and water jet. Shears are machines that cut objects using shear force. Saws cut objects with mechanical friction by rotating or reciprocating motion, and include band saw, circular saw, reciprocating saw, and wire saw. A diamond wire saw is a method of cutting objects by rotating a diamond-tipped wire. Nibbler is a tool for cutting something or making a hole by using high speed reciprocating punches and dies. Abrasive water jet is a method in which water and abrasive are injected together to cut an object. High-pressure water discharged from a pump is passed through a nozzle to generate a high-speed water stream, and the abrasive is sucked from the outside by using a negative pressure generated when the water steam is sprayed.

2.2 Thermal cutting technologies

Thermal cutting uses thermal energy to cut the object without making direct contact on the work piece. The object material is melted and removed by high-temperature heat and high-pressure gas stream. Plasma cutting, laser cutting, and oxy-fuel cutting (flame cutting) are typical thermal cutting techniques. Plasma cutting makes use of a high temperature and high flow velocity plasma stream formed by restricting an arc to a small hole of a nozzle. In laser cutting, CO_2 laser and Nd/YAG laser are mostly used for metal cutting. Oxy-fuel cutting is a technique for cutting the object by heating it with chemical reaction of oxygen and fuel and blowing high-pressure of oxygen. The flame cutting is one of the most widely used technologies for thermal cutting technology in the general industry.

2.3 Electrical cutting technologies

In electrical cutting techniques, there are metal disintegration machining (MDM), electrical discharge machining (EDM), and arc saw cutting. MDM is a method of cutting metal by supplying a constant AC power and using an electrode bar. EDM is similar to MDM, but requires a supply of limited low alternating current. Arc saw cutting is a method in which a saw blade without the teeth cut objects without contact with them. A non-consumable electrode cut objects by a high-current electric arc formed between the object and the blade.

3. Performance factors of cutting technologies

In previous studies, the evaluation factors of the metal cutting techniques is suggested as 22 factors to evaluate the cutting technologies and they were grouped into four categories such as cutting performance, location, environment, and cost impact [12, 13]. However, the previous literatures evaluated the cutting performance substantially with respect to only 4 factor groups above. Furthermore, object technologies evaluated were limited in their number. This evaluation approach in some cases is insufficient to select the optimal cutting technology out of the all technologies available and to establish a dismantling plan. Therefore, this paper have investigated wider object technologies and more factors and analyzed them with 9 factors. Those are possibility of underwater work, automation/remote control, state of development, cutting object (material and shapes including cutting depth), cutting speed, cost, quality of cut surface, secondary waste generation, and required space and ease of work, respectively. The results analyzed are shown in Table 1 [4-20].

4. Conclusions

This paper integrated and summarized the qualitative /quantitative data of each cutting technique in consideration of various factors for selecting the cutting technique according to the cutting object and conditions in dismantling of NPPs. This result can give basic data to completely evaluate the performance on the technologies and to select the optimal technology in consideration of various cutting conditions and objects. Based on these data, we will select the optimal cutting technique according to various cutting conditions in order to reduce the volume and dispose of the waste generated from decommissioning of the NPPs. The complete evaluation on whole factors to be considered is necessary in near future to select the optimal cutting technology.

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REFERENCES

[1] S. Yang, Global nuclear power plant decommissioning market, Business forum of nuclear decommissioning, 2017.
[2] J. Jang, Development of engineering system for decommissioning of nuclear facility structures, Magazine of the Korea concrete institute, Vol. 28, No. 5, pp. 15-20, 2016.
[3] IAEA, State of the decommissioning of nuclear facilities around the world, 2004.
[4] IAEA, State of the art technology for decontamination and dismantling, pp. 81, 1999.
[5] LLW repository Ltd, Management of waste failing the discrete item limit, No. 1, pp. 2–92, 2016.
[6] Fr.-W. Bach and J. Lindemaier, State of the art of thermal and hydraulic cutting techniques for decommissioning tasks in nuclear industry, 1998.
[7] F. W. Bach et al., Analysis of results obtained with different cutting techniques and associated filtration systems for the dismantling of radioactive metallic components, Commission of the European Communities, 1993.
[8] E. Suni, Classification and methods for splitting and cutting steel piles, Helsinki metropolia university bachelor's thesis, 2017.
[9] IAEA, Decommissioning of nuclear facilities: decontamination technologies, 2006.
[10] T. Mitsui et al., Cutting performance of remote fiber laser cutting system for dismantling HLW glass melter, Proceedings of waste management 2014 conference, 2014.
[11] R. W. Henderson and L. Eickelpasch, Cutting reactor pressure vessels and their internals–trends on selected technologies–10247, 36th Annual radioactive waste management symposium, 2010.
[12] L. E. Boing et al., An evaluation of alternative reactor vessel cutting technologies for the experimental boiling water reactor at Argonne national laboratory, Argonne national lab., 1989.
[13] K. Jeong et al., An evaluation of the dismantling technologies for decommissioning of nuclear power plants, Annals of nuclear energy, pp. 62-64, 2014.
[14] R. W. M. Committee and R. W. M. Committee, Remote handling techniques in decommissioning, NEA/RWM/R, Nuclear energy agency, 2011.
[15] P. E. O. Lainetti, Cutting techniques for facilities dismantling in decommissioning projects, J. Energy power eng., vol. 10, pp. 513–521, 2016.
[16] R. Borchardt and J. Raasch, Results of the full scale testing of the remote dismantling in Greifswald NPP, 2004.
[17] S. Kim et al., A state-of-the-art report on cutting technologies for decommissioning nuclear facilities. Korea atomic energy research institute, 2007.
[18] D. Krajcarz, Comparison metal water jet cutting with laser and plasma cutting, Procedia engineering, Vol. 69, pp. 838-843, 2014.
[19] Co-ordination Network on Decommissioning of Nuclear Installations (CND), Dismantling techniques, decontamination techniques, dissemination of best practice, experience and know-how, Final activity report, 2009.
[20] L. Bonavigo and M. De, Issues for nuclear power plants steam generators, Steam Gener. Syst. Oper. Reliab. Effic., 2012.

Table 1. Performance characteristics of metal cutting technologies

		Thermal cutting technologies			Mechanical cutting technologies					Electrical cutting technologies		
		Plasma Cutting	Laser Cutting	Oxy-Fuel cutting	Shears	Nibbler	Saws	Diamond Wire Saw	Abrasive water Jet	MDM	EDM	Arc Saw Cutting
Underwater		Yes [8, 14, 20] Yes(<100m) [19]	Under development [5, 8], Yes [14, 20]	Yes [8, 14] Yes, with reduced cutting speed [20]	Yes [14]	Yes [14, 17]	Yes [14]	Yes [8]	Yes [8, 14]	Yes [14]		
Necessity of additional development		No [12,14]	Yes [12,14]	No [12,14]	No [12]					No [14]	Yes [12] No [14]	Yes [14]
Automation / Remote control		Yes [8, 20], Excellent [14]	Yes [8,10], Average [14]	Yes [20], Good [14]	Yes [20], Excellent [14]	Yes, Good [14]	Yes [20], Excellent [14]	Yes [8]	Yes [8, 20], Average [14]	Yes, Average [14]		
Object (Depth of cut)	Shape	Large diameter pipes and tanks, plate and pressure vessels Simple shapes [8]	Complicated shapes [8]	Large diameter pipes and tanks, plates and pressure vessels, shafts, beams Simple shapes [8]	Large diameter pipes(300 mm) Wall(5 mm) [6]	Large diameter pipes and tanks	Complicated shapes Small diameter pipes	Thick structures and wall or floor (<60cm) Pipes, Metal	Complicated shapes [18]	All	N/A	Small diameter pipes, plates and pressure vessels
	Materials	Metal and conductive materials (< 25.4 mm) Electrically conductive material (steel, Al, Cu, STS etc. 9-50 mm) [4] All conductive materials STS(170 mm) [20] Air (160 mm), underwater (100 mm) in standard power 600A (250V)	Insensitive materials to fire [5] Steel (35mm / 5kW), CMn steel (20 mm), STS (12 mm) [5] copper, titanium, fabric, ceramic, concrete All materials (<110 mm) [20]	Objects with low thermal conductivity (No limit) Metals and conductive Materials(152.4-304.8 mm) [8]	All [14]	Mild steel, STS [14]	All materials Reciprocating saw : steel, Al, non-ferrous metal (<130 mm) [5] Wire saw : very thick metal and concretes [16]	No constraint on material and depth of objects	almost the whole materials: Air(250mm), underwater(200 mm)[6] All(< 300mm) [19] Steel(300mm in 250MPa) [11]	All [14]	All [14]	Electrical conductive materials (STS, Al, Cu etc.) (Difficult : carbon steel, Exclusion : materials including Mg, Ti, Zn) [17] The thickness is only related to the blade diameter.
Cutting speed (mm/min)		100-500 (10 mm sheet metal) [19] 460-30 (30-115 mm, underwater 10 m) [11] Slower [8]	1000 (10 mm sheet metal) [19] 300-1000 (10-100 mm STS) Fast [8,18]	350-700 (10 mm sheet metal) [19] 300-1000 (mild steel) Fast [8,18]	N/A	1000 (5 mm STS) [15]	10-2 (10-50 mm) [19]	N/A	25-115 (air), 25-105 (underwater) [7] Slow [18]	N/A	1/10 of mechanical cutting [9]	100-10 (10-50 mm) [19] 32 cm^2/s [7]

<table>
<tr><th colspan="2" rowspan="2"></th><th colspan="3">Thermal cutting technologies</th><th colspan="5">Mechanical cutting technologies</th><th colspan="3">Electrical cutting technologies</th></tr>
<tr><th>Plasma Cutting</th><th>Laser Cutting</th><th>Oxy-Fuel cutting</th><th>Shears</th><th>Nibbler</th><th>Saws</th><th>Diamond Wire Saw</th><th>Abrasive water Jet</th><th>MDM</th><th>EDM</th><th>Arc Saw Cutting</th></tr>
<tr><td colspan="2" rowspan="2">Cost</td><td rowspan="2">Medium [20]</td><td rowspan="2">High
Medium high
[20]</td><td rowspan="2">Not expensive
Cheap
low [20]</td><td>Cheap</td><td>N/A</td><td>Low operating cost</td><td>N/A</td><td rowspan="2">Higher than laser and plasma [18]
high [20]</td><td rowspan="2">N/A</td><td rowspan="2">N/A</td><td rowspan="2">N/A</td></tr>
<tr><td colspan="4">Medium high [20]</td></tr>
<tr><td colspan="2">Quality of cut surface</td><td>Thermal deformation in a wide area [18]
More rough than laser cutting
Good [8]</td><td>Thermal deformation in a small area [18]
Very good [8]</td><td>Poor, thermal deformation in a large area [8]</td><td>No thermal deformation</td><td>N/A</td><td>No thermal deformation (band saw) [19]</td><td>Rough compared to laser cutting
Not precise cutting</td><td>No thermal deformation [18]
Precision better than plasma, worse than laser</td><td>N/A</td><td>Delicate, accurate</td><td>Clear</td></tr>
<tr><td rowspan="2">Second-ary waste</td><td>Liquids</td><td>N/A</td><td>N/A</td><td>N/A</td><td rowspan="2">No secondary waste</td><td>N/A</td><td>(band saw) Cutting oil [19]</td><td>N/A</td><td>A large amount of water</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
<tr><td>Solids / gases</td><td>Working gas (N_2, inert gas) [19]
slag / sludge radiation particles of more about 5 times compare to mechanical cutting
Large amounts of contaminated aerosols [5]
6-25 g/m aerosol generation (10-50 mm cutting) [19]</td><td>Mainly fine particles like dust
Small amounts of waste [5]
Working gas [19]
Possible to reduce the amount of secondary waste</td><td>Ferritic oxide (slug) [19]
Smoke, aerosol</td><td>Easy to collect small pieces of metal removed for waste treatment, no occurrence of dust and air particles [17]</td><td>No flame generation, no radioactive contamination such as smoke or gas. (Wire saws), wire and coolant. (Reciprocating saws) dust and metal debris and machinery itself [5]
0.05-0.2 g/m aerosol (10-50 mm cutting) [19]</td><td>Dust, contaminated water or gas, contaminated wire [5]</td><td>Used abrasive post-treatment required [19]
Few air pollution [12]</td><td colspan="3">About 5 times the mechanical cutting [9]</td></tr>
<tr><td colspan="2">Required space / ease of work</td><td>Ventilation and water treatment facilities required [12]</td><td>Ventilation [12] and Filtering facilities and operator protection required [12]</td><td>Ventilation facilities required [12]</td><td>N/A</td><td>N/A</td><td>(Band saws) Easy to apply on site with various variations [19]</td><td>Ventilation and water treatment facilities required [12]</td><td>Ventilation [12] and separate device for extra high-pressure water formation required</td><td>N/A</td><td>Dielectric fluid supply, containment and processing required</td><td>Space required for blade diameter, ventilation and water treatment facilities required [12]</td></tr>
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