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ARTICLE

A Review of CFD Modeling of Erosion-induced Corrosion Formation in Water Jets Using FEA

Kadir Gok[1], *H. Deniz Ada*[2], *Nazlıhan Kilicaslan*[1], *Arif Gok*[3*]

[1] *Department of Biomedical Engineering, Engineering and Architecture Faculty, Izmir Bakircay University, Izmir, 35665, Turkey*

[2] *Chemical Technologies, Dumlupinar University, Kutahya Vocational School of Technical Sciences, Germiyan Campus, Kutahya, 43100, Turkey*

[3] *Department of Industrial Design, Architecture Faculty, Kütahya Dumlupinar University, Kutahya, 43100, Turkey*

ABSTRACT

A comprehensive review of all the related investigations carried out on water jet cutting or AWJ cutting is performed. The experimental methods and results used on this subject were examined, defined and compared by the researchers. This research shows that further improvements are possible in the water jet cutting method. In order to reduce the high cost of the empirical technique and increase the time efficiency, it is important to perform computerized Finite Element Analysis (FEA) or Computational Fluid Dynamics (CFD) based on AWJ processing. An attempt has been performed to systematically arrange the research investigations conducted on water jet cutting. The studies on the definition of nozzle failure, calculations using CFD of water jet cutting or AWJ cutting processes, and the studies on the parameters influencing water jet cutting are reviewed and the future work for the further improvement of the water jet cutting process is highlighted.

Keywords: AWJ; Computational fluid dynamics; Erosion-induced corrosion; Finite element analysis

1. Introduction

Erosion corrosion is a type of wear that occurs when a material, typically a metal, is subjected to both erosion and corrosion at the same time. This

*CORRESPONDING AUTHOR:
Arif Gok, Department of Industrial Design, Architecture Faculty, Kütahya Dumlupinar University, Kutahya, 43100, Turkey; Email: arif.gok@dpu.edu.tr

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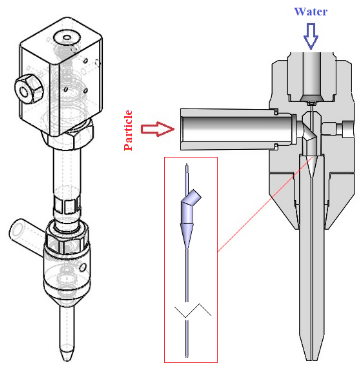
can lead to significant damage to the material and can have serious consequences for the structures and systems in which it is used. Erosion is the process by which a material is worn away by friction or abrasion, while corrosion is the chemical breakdown of a material due to its reaction to its environment. Erosion corrosion can occur in a variety of settings, but it is often a problem in areas where there is a lot of water or wind, such as near the ocean or in a desert. It can also occur in areas where there is a lot of mechanical wear, such as in pipelines or other infrastructure that is subjected to high levels of flow or pressure. There are several factors that can contribute to the development of erosion corrosion, including the composition and microstructure of the material, the pH and temperature of the environment, and the presence of corrosive chemicals or other contaminants. The severity of erosion corrosion can also be influenced by the type and intensity of the erosion and corrosion processes, as well as the duration of exposure. To prevent or mitigate the effects of erosion corrosion, a number of strategies can be employed. These include the use of materials that are resistant to erosion and corrosion, the application of protective coatings or linings to the surface of the material, and the implementation of proper maintenance and repair practices. In addition, the design of structures and systems can be optimized to minimize the risk of erosion corrosion, by taking into account the specific environmental and operational conditions in which they will be used.

Overall, erosion corrosion is a complex and multifaceted issue that requires a thorough understanding of the underlying mechanisms and factors that contribute to its development. By addressing these issues through a combination of material selection, design optimization, and effective maintenance and repair practices, it is possible to significantly reduce the impact of erosion corrosion and extend the service life of materials and structures.

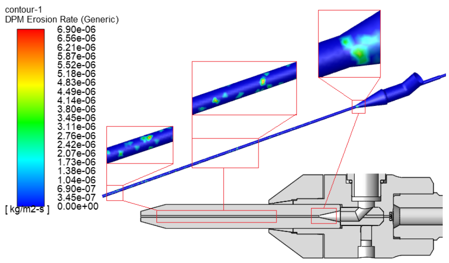
AWJ cutting is one of the new fabrication techniques used in various industrial fields. To facilitate the tool selection process, a corporeal infix should not be used as a cutter, it should be used in essential practicing functions and these functions should be able to be done in a single cutting tool. This method has advantages in terms of easy processing of hard to machine materials such as titanium alloys, no thermal stress on the material superficial and no cutting tool abrasion. It is a great advantage not to use cutting tools in modern manufacturing methods. Damage to the water jet nozzle is possible because of operations such as cutting and drilling by applying high pressure.

2. Studies on water jet cutting processes using the FEA or CFD

Lately, operating with AWJ based on FEA or CFD is crucial to decrease the high costs and increase time efficiency of the experimental techniques. Analytically, the nonlinearity of the problem adds complexity to AWJ cutting. CFD and FEA are other solutions in such cases as analytical and experimental techniques may be insufficient to specify the AWJC process. Accurate load and boundary conditions must be identified to avoid unintended consequences from these techniques [1]. FEA was used to solve many engineering problems [1-9]. There are some academic works on this topic in the literature. Liu et al. [10] investigated AWJ properties by CFD. Kumar and Shukla [11] modeled damage behavior in AWJ processing by presenting an elasto-plastic model based on an open FEA application. Abdelhameed et al. [12] investigated crater geometry in the numerically AWJ turning process. The impact efficiency of AWJ selection under limiting pressure was appraised in terms of such as the shape of the rock impact crater and rock stress, shear force [13]. Liu et al. [14] studied the stroke capacity of AWJ breaking concrete depending on its abrasive concentration. Zhang et al. [15] advanced a fluidic jet nozzle for use in manure inoculation from paddy fields by CFD. Guan et al. [16] and Cui et al. [17] conducted a numerical and empirical study of cavitation and wear of the immersed self-resonant water jet, investigating the properties of sparks and the causes of sparks at the time the AWJ process and rear mixed processing. Zelenak et al. [18] investigated continuous micro-water jet behavior using numerical modeling, computed tomography and optical diagnostic methods. Beglaryan et al. [19] predict the wear areas of a compressor wheel using CFD at high temperature and pressure by comparing it with the empirical pattern. Erosion-corrosion appearing in the nozzle AWJ process using CFD was confirmed by Ada and colleagues [8] as shown in **Figure 1(a)** and **Figure 1(b)**.



(a)

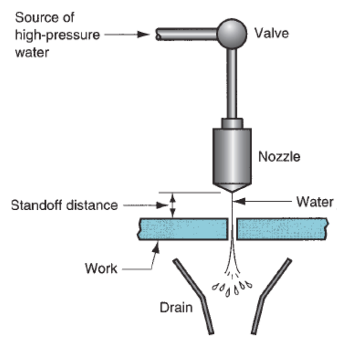


(b)

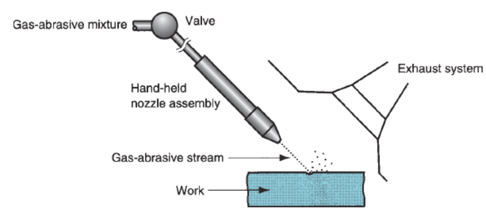
Figure 1. CFD model, (a) 3D model of AWJ [20], (b) the wear rate in the nozzle [8].

3. Studies on the parameters influencing the water jet cutting or AWJ cutting

Many factors such as cutting depth, water jet speed and nozzle diameter, abrasive type and materials are effective in water jet cutting or AWJ cutting processes. In water jet cutting, a slender, high-pressure, high-velocity stream of water is sent to the superficial of the material to cut through the material. This is shown in **Figure 2(a)**. AWJ machining is used in metallic workpieces, and as shown in **Figure 2(b)**, abrasive particles are often put in the jet stream, making cutting easier. The insert of abrasive spalls into the flow confounds the process by increasing the amount of parameters that need to be controlled. Sand size and flow rate can be added as additional parameters [21]. AWJ technique enables the processing of difficult-to-machine materials. Abdelhameed et al. [12] examined the impact of traverse velocity and jet impact angle on the erosion process in a radial mode of AWJ processing as shown in **Figure 3**. Perez et al. [22] examined the effect of key processing variables such as abrasive flow rate, studied nozzle diameter and length on abrasive water suspension and aluminum cutting depth. Parikshit studied the impact of AWJM variables on mild steel cutting by optimizing process parameters [23]. Babu et al. [24] examined the impact of processing parameters with Response Surface Method. Shipway et al. [25] informed that high motion speed should be used in order to achieve low waviness in processing titanium alloys. Lima et al. [26] examined the line that occurred and superficial asperity on gemstones. They saw that the surface asperity and lines could be reduced by increasing the traverse speed of the largest variables on the superficial they examined. Wang [27] found that high traverse speed rises the amount of asperity when processing polymer matrix composite materials. Azhari et al. [28] achieved that superficial asperity and strictness reduced with a rise in feed rate on aluminum alloy 5005.



(a)



(b)

Figure 2. (a) The water jet cutting, (b) the AWJ cutting [21].

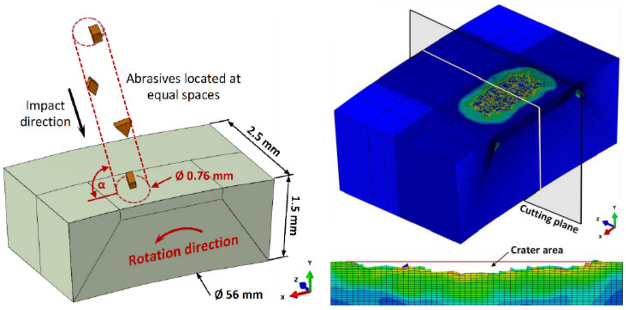


Figure 3. 3D view of a simulation example [12].

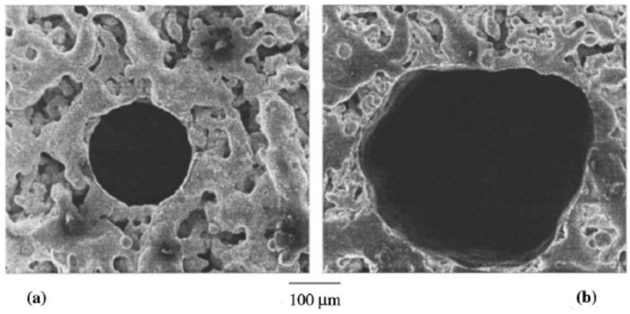


Figure 5. SEM images of nozzle outlet recorded before (a) and (b) after 105 minutes of testing using abrasive slurry but without any oil injection [29].

4. Studies on the nozzle failure in the water jet cutting or AWJ cutting

In particular, there are many experimental, analytical and numerical studies on this issue, as nozzle failure is very important in terms of cost in AWJ processing. Nozzles impress the sensibility, efficiency and cost of the AWJ cutting. That is why it is crucial that they be short-lived. Moreover the ejection of materials from the nozzles creates sliding contact on both superficies and the nozzles wear out. This leads to a decrease in the quality of the cutting superficies and undesirable changes in the geometry of the working surfaces. In other words, the lifetime of the nozzles in AWJ practices is approximately 100 hours. **Figure 4** also shows the silicon casting of the sectional nozzle and WC. A study by Anand and Katz described a new process to avoid nozzle erosion in AWJs [29]. There are SEM photos of nozzles in **Figure 5**.

In **Figure 6**, the wear rate in the nozzle was figured out as 6.90 × 10^6 kg/m^2 sec. This value was altered as 0.30 mm (27.09 mm yearly) with an advanced application for 100 hours [8].

Figure 4. The segmented nozzle and the silicone molding of WC [30].

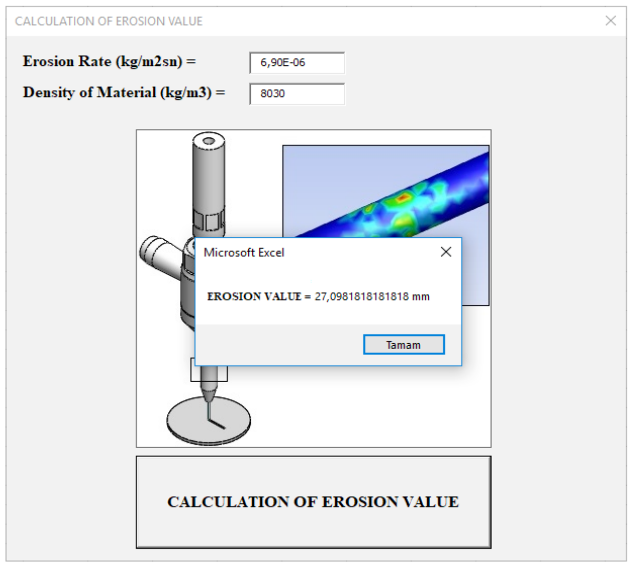


Figure 6. Calculation of yearly erosion value [8].

Figure 7 appears the SEM of the nozzle inlet profiles for uneroded and eroded Al_2O_3/(W, Ti)C and B4C nozzles. It is understood that the flow is turbulent, and the inlet profile of the eroded ceramic nozzle is not homogenous [31].

The smooth particle hydrodynamics (SPH) technique was used to form the AWJ impact concrete model to examine the effect of corrosive concentration on the crushing force, concrete internal energy, corrosive spall distribution, impact depth, and detriment and impact performance under different concrete compressive strengths and abrasive intensities as shown in **Figure 8** [14].

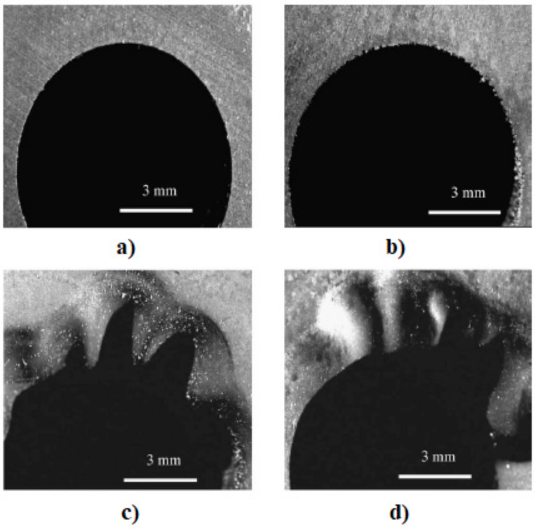


Figure 7. Nozzle inlet profiles of a) uneroded Al_2O_3/(W, Ti)C nozzle, b) uneroded B4C nozzle, c) eroded Al_2O_3/(W, Ti)C nozzle after sand blasting for 8 h, d) eroded B4C nozzle after sand blasting for 4 h [31].

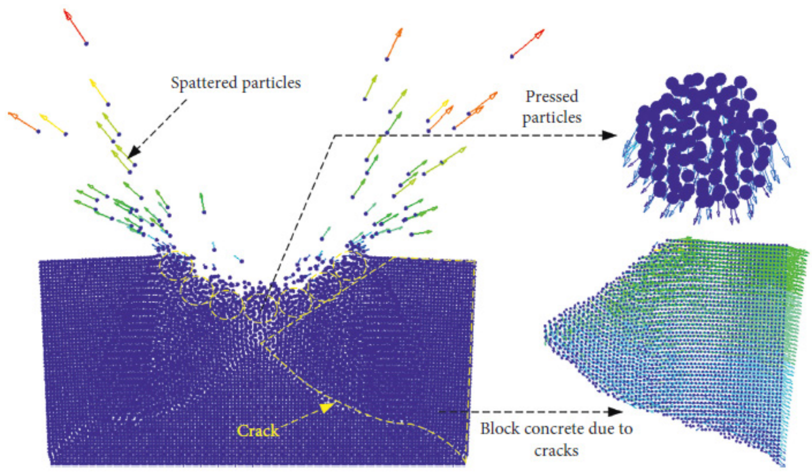


Figure 8. Concrete material speed vector (20 MPa, abrasive concentration 20%) [14].

5. Conclusions and future plans

In the article shown, the following conclusions were reached in water jet or AWJ cutting, which were examined in all aspects.

The study showed that abrasive types have a very significant effect on crater geometry. Globe abrasive kind is more favorable in terms of crater spherical than other abrasive kinds. Different abrasive kinds do not affect crater depth.

The study shows that nozzles are an important solution for calculating erosion-induced corrosion when treated with AWJ.

The influence of process factors on the crater geometry is very beneficial in understanding the AWJ cutting process.

The amount of nozzle wear of abrasive water suspension jets can significantly reduce with the help of porous lubricated nozzles.

The hardness of the nozzles is important in terms of erosion wear in sandblasting processes.

Due to the more intrusive particles, the concrete was more easily crushed and damaged.

Based on the above literature review, recent developments of water jet or AWJ cutting are shown in **Table 1**. Water jet cutting operations have started to be used in surgical processes with the developing technology. Further, we are thinking to study this practice on human bone and soft tissues.

Table 1. Recent developments of water jet or AWJ cutting.

Authors	Base Material	Objective	Process Parameter	Outcome
Liu H, Wang J, Kelson N, Brown RJ (2004)	Water and spalls within a jet.	A essential data of the ultrahigh speed jet dynamic properties such as the speed distribution.	The different flow conditions were simulated.	The velocity reduction for fragments of different sizes was similar, but less than the corresponding water velocity, and smaller diameter fragments decelerated faster than larger fragments.
Kumar N, Shukla M (2012)	Grade 5 Titanium alloy (Ti-6Al-4V)	The practice of an elasto-plastic pattern based overt FEA to model the wear type in processing using AWJ.	The influence of abrasive spall impact angle and speed on the crater globocity and depth, and wear rate	The conclusions of the analyzing specify an important diversity of crater geometry for crush of up to the first 17 spalls, depending on crushing speed and angle.
Abdelhamed Y, Hassan A, Kaytbay S (2019)	AISI 4340, The material model of Johnson-Cook (JC)	The crater geometry investigated for AWJ turning process.	Traverse speed (mm/s), Jet impact angle (deg)	Increasing the traverse rate would decrease the crater area.
Liu S, Cui Y, Chen Y, Guo C (2019)	Ambrasive jet, Water, Rock	The mashhing efficiency of the AWJ was evaluated from such angles as limiting pressure, shear force, rock mashing crater shape and rock stress.	The pressure increasing from 0 MPa to 62.5MPa	High pressure AWJ decreases the sensibility of rock strength to environmental pressure and provides better rock breaking efficiency.
Liu X, Tang P, Geng Q, Wang X (2019)	AWJ, concrete.	Investigate the influence of abrasive intensity on stroke efficiency of AWJ impacting concrete.	The stroke force, concrete internal energy, impact depth.	The intruding spalls nearly rise commensurately with the abrasive intensity, which effectually expounds the rising trend of the impact depth and detriment.
Zheng W, Jiang Y, Ma X, Qi L (2019)	Urea Ammonium Nitrate solution.	The present broadcasting proccess for chemical manure practics for rice generation causes important nitrogen losses through volatilization. To diminish this issue, a liquid-jet nozzle was advanced for inoculation of fluidic manure in paddy fields.	mass flow rates, velocity, manure inlet diameter (df) and nozzle orifice diameter.	From one kind of fluidic manure and one soil condition, and the simulation conclusions were not confirmed for all the probable designs. Attention should be taken when practicing the conclusions. Inaculation of fluidic manure using the liquid-jet technology is a highly hopeful method for rice generation.
Guan J, Chen X, Duan J, Gu K, Shen T (2019)	Gasoline leakage, AWJ.	The aim is to analyze the properties and mechanism of formation of the sparks generated by the back-mixed AWJ (AWJ).	Temperature characteristics of sparks.	The properties and production process of the sparks produced by the rear-mixed AWJ have been examined.

Table 1 continued

Authors	Base Material	Objective	Process Parameter	Outcome
Cui L, Ma F, Cai T, Pan Y, Liu B, Qiu L (2019)	Simulated deep sea environment, CFD	Investigate the cavitation of a self-resonating water jet.	Frequency bands of numerical simulations, validate the proposed scheme.	Frequency bands of numerical simulations were in decent conformity with empirical data. Based on this, we acquire the pouring frequency of the bubbles, studied the wear influence.
Zelenak M, Riha Z, Soucek K, Pude F, 2019	Water, PMMA	The study is concerned with the application of numerical modeling, computed tomography and optical diagnostic methods for the study of persistent micro water jet behavior.	Flow rate, pressure	The conclusions and resolves of the micro CWJs flow based on numerical modelling, visualization and observing very good agreement of theoretical and applied tests.
Biglarian M, Momeni Larimi M, Ganji B, Ranjbar A (2019)	Al_2O_3	Abrasive wear is one of the causes for reduced performance in centrifugal compressors. In the existence of suspended solid spalls model the degradation of distinct components of the compressor in the liquid, particularly the propeller blades	The Eulerian–Lagrangian approximation is used in fluid simulation and spalls pursuing	CFD conclusions that high wear rate emerges at impeller eye and blade roots are in a decent conformity with empirical model.
Ada HD, Erdem M, Gok K (2021)	The fuid (water) and steel (AWJ and the particulate type).	Corrosion due to erosion nozzle simulated in computer environment.	With a CFD model developed to measure erosion-induced corrosion AWJ processing simulated.	The study shows that calculating the corrosion due to erosion of nozzles with CFD when treating with AWJ is an important solution.

Conflicts of Interest

Author Kadir Gok reports that he has no conflicts of interest. Author H. Deniz Ada reports that he has no conflicts of interest. Author Nazlıhan Kilicaslan reports that he has no conflicts of interest. Author Arif Gok reports that he has no conflict of interest.

Ethical Approval

This article does not consist of any studies with a living being did by any of the authors.

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