Design and Simulation of Nozzle for Pure Water Jet Portable Cutting Tool

Razali Abidin, Mohamad Asmidzam Ahamat, John Paul, Al Imran, Tarmizi Ahmad, Hafizi Nordin,Wan Hanif Wan Yaacob

Abstract—A pure water jet at subsonic speed provides an opportunity for application in cutting soft material with the advantage of not contaminating the workpiece. Inside the nozzle, water is flowing through various cross sections, which lead to pressure drop and loss of energy. This requires a nozzle with a design that causes minimum pressure drop. In this work, Computational Fluid Dynamics (CFD) and Finite Element Analysis (FEA) were used to analyse the flow through five different nozzles. For each nozzle, the pressures of 10 MPa, 20 MPa and 30 MPa were applies at the inlet. For the inlet pressure of 10 MPa, the highest outlet velocity us 136.12 m/s at the pressure of 9.261 MPa. The impact pressure at stand distance of 0.5 mm and 1.0 mm were 8.26 MPa and 8.02 MPa, respectively. For this nozzle, the Factor of Safety for 10 MPa, 20 MPa and 30 MPa were 6.4, 3.2 and 2.961, respectively. The findings are relevant to the development of pure water jet cutting machine.

Index Terms: factor of safety, inlet pressure, nozzle, pure waterjet, outlet pressure

I. INTRODUCTION

In cutting process, mechanical related methods are exposed to excessive tool wear and significant increase in local temperature. A worn cutting tool requires higher cutting force and produces surface finish with poor quality that leads to higher operating cost due to additional energy consumption and higher rejection rate of parts. These issues could be eliminated by using cutting system that utilizes high pressure water jet. High-pressure water jets are widely used in various mechanical works such as in cutting, cleaning and surface treatment. The use of high-pressure water jet does not increase the local temperature of work piece, subsequently eliminate thermal distortion.

Cutting process using high velocity water stream with or without abrasive remove the material that is being cut through erosion. High-pressure water is forced to flow through a small hole, which converts the pressure into kinetic energy. This requires hard material such as tungsten carbide and hardened steel to withstand the high pressure and abrasive environment if the fluid is mix with abrasive particles. However, abrasive condition does not exist in pure water jet cutting machine. Although pure water jet cutting machine is only relevant for the cutting of soft material such as meat. In this machine, it is common to pressurize the water to 1300 to 6200 bar that will flow through a hole with diameter of 0.18 mm to 0.4 mm. A high velocity water stream is produced, approaching the speed of sound. For a lower pressure (~10 MPa), the velocity of water jet can reach up to 133 m/s [1]. This water jet can cut one-inch polystyrene, 4 mm mounting board and 1-inch sponge.

Tungsten carbide is appropriate for operating with unfiltered water at the pressure below 140 MPa) [2]. Steel has the operating pressure like tungsten carbide but the water must be filtered to 25 micron or better. For operation with pressure that is higher than 140 MPa, sapphire can be used provided the water is filtered to 10 micron or better. The properties of these materials enable them to have a good wear resistance for filtered and unfiltered water [3].

This paper concerns the simulation of pure water nozzle for portable cutting tool. Five designs of nozzle were evaluated to determine the suitable material, velocity and von Mises Stress.

II. DESIGN OF NOZZLE

Five designs of nozzle (Fig. 1 to Fig. 5) were modelled in the software. Two materials were used for the nozzle, which are aluminum alloy (5052-H321) and stainless steel 309(for Nozzle 1 only). The mesh applied to nozzles is as shown in Fig. 6. Static simulation analysis was conducted to identify the stresses within nozzle due to the force or pressure of water. The yield criterion and the von-misses were observed to identify any possibility of failure, when the von-misses stresses exceed the yield point of the material. Static loading of 10 MPa, 20 MPa and 30 MPa was applied to internal parts of the nozzle. The analysis of flow was done in Fluent, where the pressure and velocity were evaluated.

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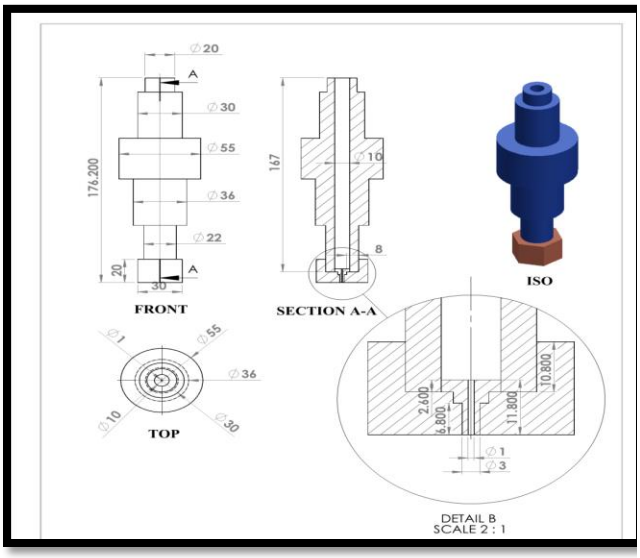

Fig. 1: Geometry of Nozzle 1

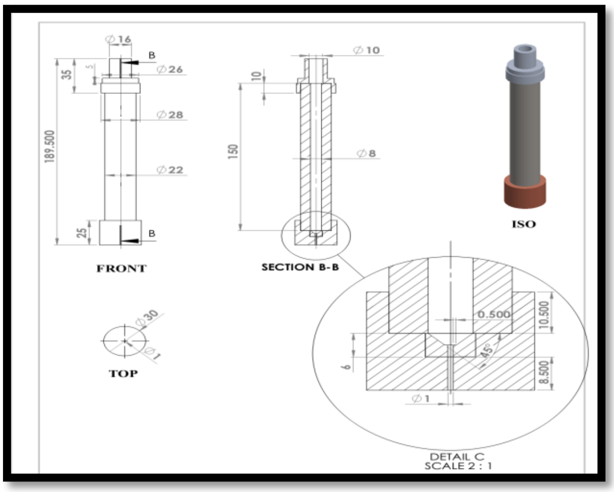

Fig. 2: Geometry of Nozzle 2

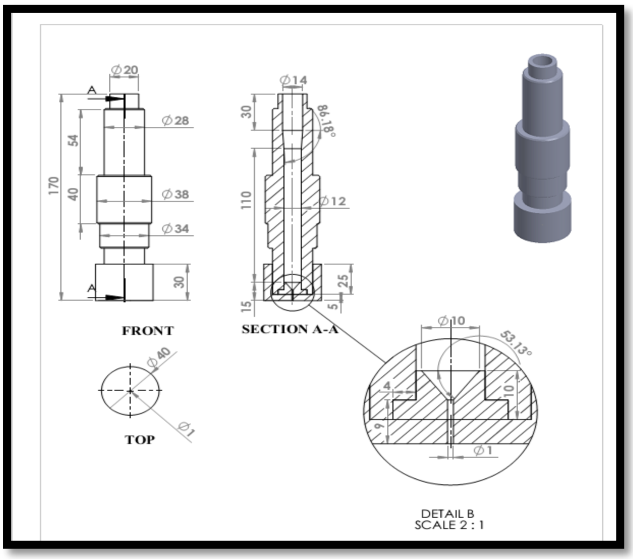

Fig. 3: Geometry of Nozzle 3

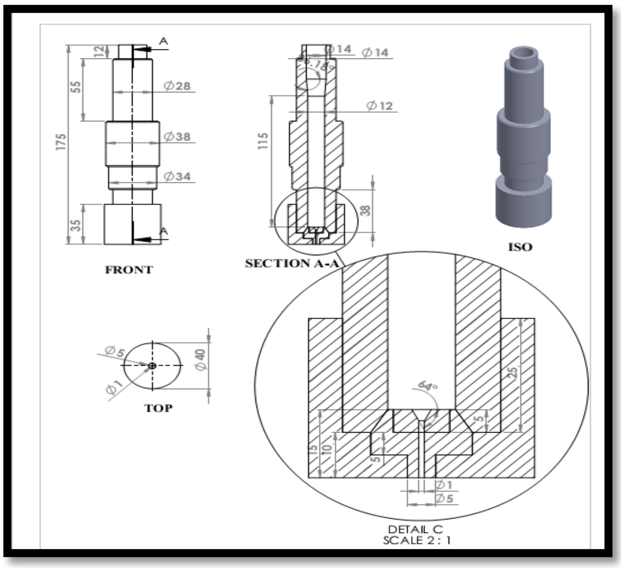

Fig. 4: Geometry of Nozzle 4

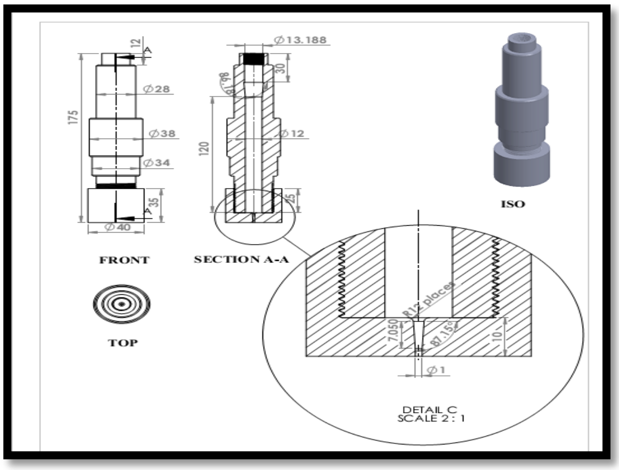

Fig. 5: Geometry of Nozzle 5

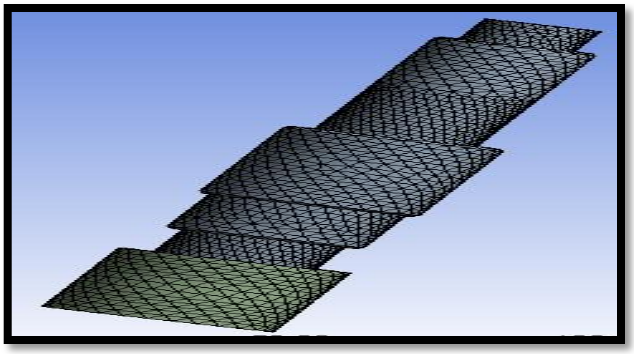

Fig. 6: Meshing of nozzles assembly parts

III. RESULTS AND DISCUSSION

Table 1 shows the parameters of simulation and results obtained for geometries of nozzles at various pressure and stand distance. For Nozzle 1, aluminum alloy (5059-H321) and stainless steel 309 were used. In general, pressure impact increase as the inlet pressure increase. The stand distance of 0.5 mm has higher pressure impact compared to 1 mm stand pressure. The Factor of Safety decreases as the inlet pressure increase with lowest of 1.9. For the average velocity, it does increases at higher inlet pressure.

The average outlet velocity for all types of nozzle is increases as the inlet pressure increases (Fig. 7). Nozzle 5 has the highest average outlet velocity for every inlet pressure. The ratio of average outlet velocity is as expected from the general energy equation, where the 30 MPa produce a velocity of ~ 1.7 times of the velocity of 10 MPa. This shows that the pressure drop within the nozzle is less significant at these pressures for all types of nozzle.

The impact pressure for 30 MPa inlet pressure is ~3 times higher than the impact pressure of 10 MPa (Fig. 8). As the average outlet velocity, Nozzle 5 produces the highest impact velocity for all initial pressures. The impact pressure is affected by the stand distance. For the stand distance of 0.5 mm (Fig. 9), its impact pressure is about 3% higher than the impact pressure for 1.0 mm stand distance (Fig. 10), for the same inlet pressure. There is no effect of stand distance on average outlet pressure.

Table 1: Parameters and results of simulation

Nozzle Design	Materials	Inlet Pressure (MPa)	Max Von mises Stress (MPa)	Total Deformation (mm)	Safety Factor	Average Velocity (m/s)	Total Pressure (MPa)	Nozzle Design & Material	Stand Distance (mm)	Pressure Impact (MPa)
1	Aluminum Alloy (5059-H321)	10	28.111	0.0017231	9.9606	105.547	5.63569	1- For Aluminum Alloy (5059-H321) and Stainless Steel 309	0.5	5.182
	Tensile Yield Strength : 280Mpa	20	56.221	0.0034462	4.9803	150.241	11.372422			10.4855
	Tensile Ultimate Strength: 310Mpa	30	84.332	0.0051693	3.3202	184.417	17.139782			15.9
	Stainless Steel 309	10	28.179	0.0006622	7.346	105.547	5.63569		1	4.5323
	Tensile Yield Strength : 207 Mpa	20	56.357	0.0013244	3.673	150.241	11.372422			9.13293
	Tensile Ultimate : 586 Mpa	30	84.536	0.0019866	2.4487	184.417	17.139782			13.5512
2	Aluminum Alloy (5059-H321)	10	37.632	0.0018184	7.4405	106.94818	5.78393	2- For Aluminum Alloy (5059-H321)	0.5	5.5878
	Tensile Yield Strength : 280Mpa	20	75.263	0.0036368	3.7203	151.83174	11.6598			11.612
	Tensile Ultimate Strength: 310Mpa	30	112.9	0.0054552	2.4802	186.3584	17.56669			16.6771
	Aluminum Alloy (5059-H321)	10	37.632	0.0018184	7.4405	106.94818	5.78393		1	4.54122
	Tensile Yield Strength : 280Mpa	20	75.263	0.0036368	3.7203	151.83174	11.6598			9.15594
	Tensile Ultimate Strength: 310Mpa	30	112.9	0.0054552	2.4802	186.3584	17.56669			13.7726
3	Aluminum Alloy (5059-H321)	10	49.052	0.0028782	5.7083	121.92809	7.47761	3- For Aluminum Alloy (5059-H321)	0.5	7.11
	Tensile Yield Strength : 280Mpa	20	98.103	0.0057563	2.8541	173.17232	15.0833			14.5495
	Tensile Ultimate Strength: 310Mpa	30	147.15	0.0086345	1.9028	212.60106	22.7732			22.7405
	Aluminum Alloy (5059-H321)	10	49.052	0.0028782	5.7083	121.92809	7.47761		1	5.307
	Tensile Yield Strength : 280Mpa	20	98.103	0.0057563	2.8541	173.17232	15.0833			10.8633
	Tensile Ultimate Strength: 310Mpa	30	147.15	0.0086345	1.9028	212.60106	22.7732			16.6122
4	Aluminum Alloy (5059-H321)	10	49.024	0.002879	5.7115	121.592	7.41739	4- For Aluminum Alloy (5059-H321)	0.5	6.8786
	Tensile Yield Strength : 280Mpa	20	98.048	0.0057581	2.8557	173.006	15.0129			13.6604
	Tensile Ultimate Strength: 310Mpa	30	147.07	0.0086371	1.9038	212.585	22.6648			20.9219
	Aluminum Alloy (5059-H321)	10	49.024	0.002879	5.7115	121.592	7.41739		1	5.15207
	Tensile Yield Strength : 280Mpa	20	98.048	0.0057581	2.8557	173.006	15.0129			10.2922
	Tensile Ultimate Strength: 310Mpa	30	147.07	0.0086371	1.9038	212.585	22.6648			16.1263
5	Aluminum Alloy (5059-H321)	10	39.063	0.0010167	6.4	136.118	9.2608	5- For Aluminum Alloy (5059-H321)	0.5	8.256
	Tensile Yield Strength : 280Mpa	20	98.048	0.0020334	3.2	193.005	18.6157			16.6854
	Tensile Ultimate Strength: 310Mpa	30	117.19	0.0030501	2.1333	236.709	27.9987			25.1919
	Aluminum Alloy (5059-H321)	10	39.063	0.0010167	6.4	136.118	9.2608		1	8.01619
	Tensile Yield Strength : 280Mpa	20	98.048	0.0020334	3.2	193.005	18.6157			16.0126
	Tensile Ultimate Strength: 310Mpa	30	117.19	0.0030501	2.1333	236.709	27.9987			24.1496

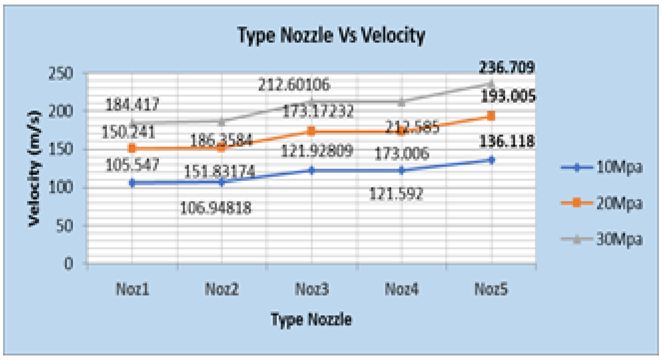

Fig. 7: Comparison of average outlet velocity of five designs of nozzle at 10 MPa, 20 MPa and 30 MPa

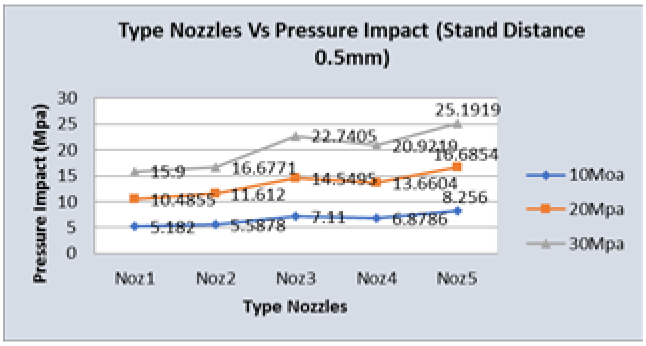

Fig. 8: Comparison of pressure impact of five designs of nozzle at 10 MPa, 20 MPa and 30 MPa

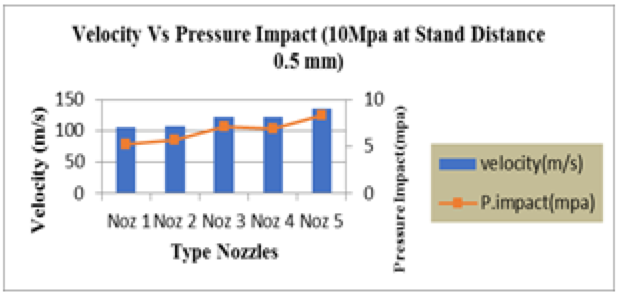

Fig. 9: Impact pressure and average outlet velocity at stand distance of 0.5 mm

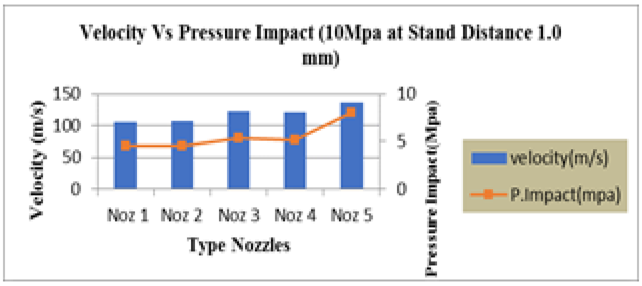

Fig. 10: Impact pressure and average outlet velocity at stand distance of 1.0 mm

IV. CONCLUSION

The factor of safety, impact pressure and average outlet velocity of five designs of nozzle were investigated. It was found that the Factor of Safety decreases to 1.9 as the inlet pressure increases. However, this is still acceptable for nozzle design. The impact pressure is affected by stand distance where slight reduction was observed at a lower inlet pressure. For the average outlet velocity, the ratio of velocity produced by 30 MPa is about 1.7 times higher than the one with 10 MPa. There is no reduction in average outlet velocity was observed between 0.5 mm and 1.0 mm stand distance. The findings obtained from this work is applicable to the design of pure water jet cutting machine.

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