International Journal For Technological Research In Engineering
Volume 7, Issue 2, October-2019 ISSN (Online): 2347 - 4718

REVIEW AND OPTIMIZATION OF PROCESS PARAMETER OF ABRASIVE WATER JET MACHINE USING MULTI CRITERIA DECISION MAKING METHOD ON ALUMINUM 5083

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ABSTRACT: This paper presents Abrasive water jet machining is the one of the recent non-traditional manufacturing technologies. It employs mixture of high pressure water and abrasive to remove the materials at high rate without distortion and microstructure changes. Flexibility of the process explores its potential for shape machining of brittle and ductile material like aluminium, ceramic and glasses. Experiments investigations should conduct to assess the influences of Abrasive Water Jet machining process parameter on MRR, SR, KW. The approach is based on Multi Criteria Decision Making Method to optimize the AWJM process parameter for effective machining. It was found the process parameters are Traverse Speed, Stand-of-Distance and Abrasive Flow Rate. Types are effective to evaluate criteria of the MRR, SR, KW. Work piece material is AL-5083. The full factorial method used for designing experiment and optimum results can be achieved by AHP/MOORA and TOPSIS method.
Keywords: AWJM, TS, AFR, SOD, MCDM, AHP/MOORA, TOPSIS.

I. INTRODUCTION

Theoretical Background

Abrasive Water jet (AWJ) machine uses cold supersonic abrasive erosion to cut almost any materials both metals and non-metals and so it is also understood as a 'blast' erosion process in which the highly pressurized water is forced through a tiny areas resulting in formation of water jet. Abrasive garnet is mixed to this jet in the mixing chamber making it an Abrasive Water jet which erodes away the material. A considerable amount of work has been conducted in recent years to study the mechanism of AWJ cutting and to develop kerf geometry and surface roughness models for process control and optimization. These have involved the processing of ductile and brittle materials, leathers, woods and rubbers, as well as composites and layered composites. which are very difficult to machine It is interesting to note, however, that very little has been reported on the AWJ cutting of thin sheet steels .Here a study of Abrasive Water jet cutting of brittle and ductile materials is done which examines the cutting performance as assessed by the various kerf characteristic measures (i.e. kerf shape and quality) and the effect of process parameter on the kerf characteristics is being studied.

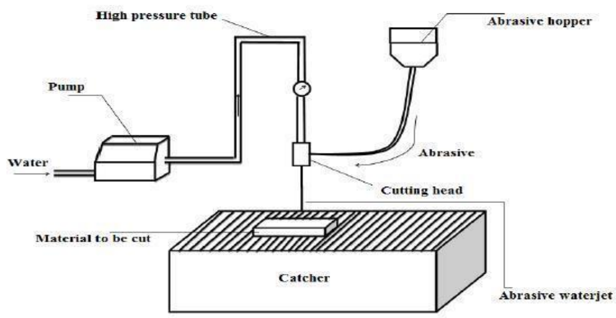


Figure 1.1: AWJM Process

History of Abrasive Water Jet Technology

Franz in 1968 was the first person who initiated the modern water jet technology. In the early 1970's, water jet cutting machines started to operate for cutting wood and plastics. It was soon discovered that the cutting process can be made more effective by introducing abrasives such as garnet into the water stream, i.e. the technology evolved to the abrasive water jet (AWJ) cutting technology. More attention started to be paid to the AWJ cutting technology in the mid to late 1970's because of the requirement for a more efficient way to cut hard materials, such as stones, compared with the traditional diamond coated saws. However, this technology was not widely accepted by industry till the ultrahigh pressure pumps became commercially available in the mid 1980's. Today, as one of the most recently developed non-traditional cutting processes, AWJ machining technology has been found to have extensive applications in manufacturing industries for machining a wide range of metals and non-metals by using a fine jet of ultrahigh pressure water-abrasive slurry. It has been particularly used in cutting 'difficult-to-cut' materials such as ceramics and marbles, and layered composites. It also allows the flexibility of cutting intricate shapes. Over the last decades, considerable research and development effort has been made to understand this machining process and the associated sciences.

II. PRINCIPLE OF OPERATION

An abrasive jet starts out the same as a pure water jet. As the thin stream of water leaves the nozzle, abrasive is added to the stream and mixed. The beam of water accelerates abrasive particles to speeds fast enough to cut through much harder materials. The mixing of abrasive particles in water jet is in such a manner that water jet's momentum is transferred to the abrasives. The coherent, abrasive water jet that exits the AWJM nozzle has the ability to cut various materials, such as metals, glass, ceramics and composites.

Process Description of AWJM
The basic technology is both simple and extremely complex. At its most basic, water flows from a pump, through plumbing and out a cutting head. It is simple to explain, operate and maintain. The process, however, incorporates extremely complex materials technology and design. There are two ways or systems in which the abrasives are mixed with the water to form an AWJ, one is the entrainment system and the other is the direct pumping system.
In an entrainment system, a high pressure water jet is formed first by an orifice; abrasives are then entrained into the water jet to mix with the water jet and form an abrasive water jet.

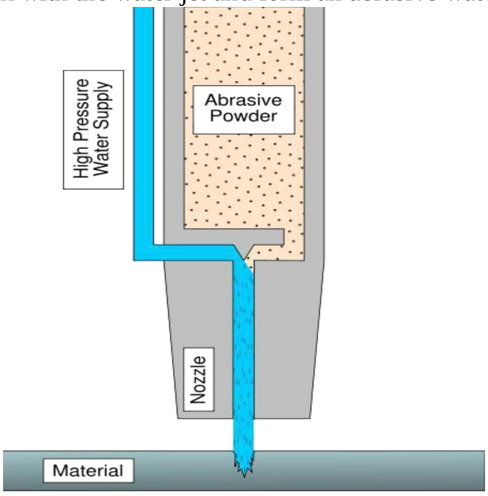


Figure 2.1: Principle of Operation

In a direct pumping system, abrasives are pre-mixed with water to form slurry that is then pumped and expelled through a nozzle to form an abrasive slurry jet (ASJ). A description of these two systems is given below.

Entrainment System
The entrainment abrasive water jet system is being widely used in the manufacturing area. The water pressure in this system is in the order of 400 MPa (or 55,000 to 60,000 psi). This high-pressure water is focused through a small precious stone orifice to form an intense water stream or water jet, as shown in Figure 2.1. The stream moves at a velocity of up to 2.5 times the speed of sound, depending on the water pressure. As the water jet passes through a mixing chamber, it mixed with the abrasive particles that are entrained into the mixing chamber through a separate inlet to the vacuum created by the water jet. Typical AWJ particle velocities range from 450 to 720m/s. The material removal takes place due to the erosion of target material by particles. Each particle contributes to the cutting process and the integration of all cutting actions by a large number of particles (in the order of 105 particles per second) can remove material at a high rate.

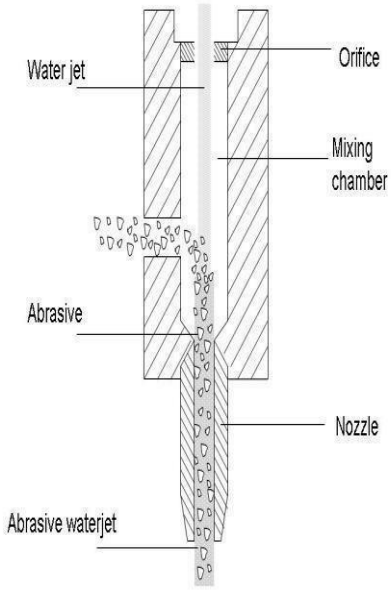


Figure 2.2: Entrainment system

As the vast majority of the abrasive water jet cutting applications use the entrainment system, this paper will study the various aspects of the technology for entrainment abrasive water jet systems. The investigations reported in the literature in relation to this type of system will be reviewed and discussed in detail in later sections.

III. EXPERIMENTAL SETUP

AWJ Machine
The experiments are designed and carry out in the Shree Gajroop Enterprise which is placed in Plot No 246 G.I.D.C., Ramangamdi Por Vadodara. The primary goal of the dissertation work is to predict the Surface Roughness, Material Removal Rate and Kerf Width. The work is carried out in S3060 using Aluminium 5083 material by varying machining parameters. One of the current challenges faced by AWJM users is the quality of parts produced, which is allied with the accurate application of the specified performance. In this study, Material Removal Rate, Surface Roughness and Kerf Width are considered as measure of part quality in accordance to industrial requirements. To achieve this, the present chapter describes the materials used for AWJM part machining.

Figure 3.1: AWJM S3060

Machine Specifications:

Table 3.1: Specifications of S3060 Machine

Specifications	
Parameters	Range
Pump Pressure	6200 bar
Cutting Area	3m to 6m
Accuracy	±0.05mm
Rapid Traverse maximum Speed	10 m/min
Axis of Rotation	2 Axis rotated Automatically (X- Axis, Y-Axis) 1 Axis rotated Manually (Z-Axis)
Abrasive Material	Garnet

Range of Input Parameter:

Factor	Range
Stand-off Distance	3 to 5mm
Traverse speed	180mm/min to 300mm/min
Abrasive flow rate	4 to 8 gm/sec

Output Measuring Parameter:

- Material Removal Rate(MRR)(mm^3/sec)
- Surface Roughness(SR) (μm)
- Kerf Width (KW) (mm)

Design of Experiment (DOE):

Series of runs or tests in which purposefully make changes to input variables simultaneously and observe the responses. Designed experiment an efficient approach for improving a process because any change more than one factor at time to quickly obtain meaningful results and draw conclusions about how factors interact to affect the response.

Types of experimental designs:

- Factorial design
- Two level factorial design
- Taguchi orthogonal arrays
- Response surface method designs

For experiment orthogonal L27 array selected with 3 factors (parameter) and 3 level of the parameter.

Table 3.2: Level of selected factors

Factors	Unit	Level		
Traverse Speed	mm/min	180	250	300
Abrasive flow rate	gm/sec	4	6	8
Stand-off distance	mm	3	4	5

Fixed parameter:

Machine Impact Angle	90
Depth of cut	10mm
Nozzle Diameter	0.7mm

Based on above factor and level orthogonal array for experiment created by MINITAB 18 software using Factorial Design which given below in Table

Table 3.3: Orthogonal L27 array

Exp. No	Traverse Speed [mm/min]	Abrasive flow rate [gm/sec]	Stand-off distance [mm]
1	250	8	3
2	300	8	3
3	300	6	3
4	300	4	4
5	180	8	3
6	300	6	5
7	250	4	3
8	180	4	5
9	250	8	5
10	180	4	3
11	250	6	3
12	180	6	5
13	300	4	3
14	180	6	3
15	180	4	4
16	180	8	5
17	300	4	5
18	250	8	4
19	180	8	4
20	250	4	5
21	300	8	4
22	300	8	5
23	250	6	5
24	180	6	4
25	300	6	4
26	250	4	4
27	250	6	4

Experimentation:

The experiments are designed and carry out in the Shree Gajroop Enterprise which is placed in Plot No 246 G.I.D.C.,Ramangamdi Por Vadodara. Input parameter set given to AWJM as per DOE table 3.3and during the each experiment time to cutting the workpiece is noted. After Experimentation measuring output parameter MRR, Surface roughness and Kerf Width mention as below.

MRR measurement:

MRR defined as material volume removed per unit time.

So

$$MRR = \frac{W_b - W_a}{\rho T}$$

Where,

$Wb = Weight\ before\ Experiment$

$Wa = Weight\ after\ Experiment$

T= Time taken to cut

ρ= Density of material 2.65gm/cm^3

For weight measurement before and after experiment of workpiece weight balance machine is used from Shree

Gajroop Enterprise.

Surface Roughness Measurement:
Surface of machined side of workpiece measured by the Surface Tester at Cipriani Harrison Valves Pvt. Ltd.

Working Principle
When the pickup was driven by drivers making a linear uniform motion along the testing surface, the, stylus which touches with the work surface moves up and down along the surface perpendicularity. Its motion is converted into electric signals, which are amplified, filtered and transformed into signals through A/D. The signals are then processed by current into Ra and Rz values before being displayed on the screen and its technical specifications are displayed below in Table 3.4.

Table 3.4: Technical Specification of Surface Roughness Tester

Specification	Units
Rating	9 V, 500 ma
Supply Voltage	100 V, 120 V, 230 V
Operating Temperature	5° c to 40 ° c
Built In Battery	Ni-h
Charging Hours	15
Charging Temperature	5° c to 35 ° c
Measuring Range	8 μm to 2400 μm
Stylus Material	Diamond
Tip Radius	40mm
Ra (Param eter)	0.01 μm to 100 μm
Return	0.8 mm/s
Detector Retraction Function	Stylus up
Traversing Speed	0.05 mm/s to 1mm/s

After the measuring number of samples through surface roughness tester (SJ-400) and considered their average value.


Figure 3.2: Surface Roughness Tester

Kerf width
It is the width of material that is removed by a cutting Process. Kerf width is measured by Digital vernier caliper.
0


Figure 3.3: Digital vernier caliper

Experimental Results of Al 5083 Material

Table 3.5: Experimental Results of Al 5083 Material

Exp. No	Traverse Speed [mm/min]	Abrasive flow rate [gm/sec]	Stand-off distance [mm]	MRR [mm^3/sec]	Surface Roughness [μm]	Kerf Width [mm]
1	180	4	3	52.83	4.98	1.98
2	180	6	3	42.35	6.59	1.99
3	180	8	3	45.28	5.53	2.45
4	180	4	4	57.17	7.77	2.79
5	180	6	4	59.19	5.72	3.70
6	180	8	4	56.60	6.15	3.13
7	180	4	5	38.50	6.41	2.13
8	180	6	5	56.04	5.68	2.56
9	180	8	5	60.98	6.34	3.74
10	250	4	3	64.15	3.40	4.14
11	250	6	3	60.98	5.37	3.20
12	250	8	3	52.83	6.35	2.61
13	250	4	4	51.79	5.97	2.31
14	250	6	4	56.60	5.29	2.44
15	250	8	4	53.90	4.56	2.42
16	250	4	5	56.60	5.45	2.03
17	250	6	5	53.36	5.38	1.05
18	250	8	5	56.04	6.24	1.57
19	300	4	3	53.36	4.13	2.26
20	300	6	3	41.50	5.48	2.02
21	300	8	3	44.39	6.63	2.23
22	300	4	4	42.79	4.07	1.95
23	300	6	4	45.49	5.40	1.36
24	300	8	4	49.32	3.39	1.43
25	300	4	5	30.49	4.70	2.21
26	300	6	5	56.60	5.41	2.44
27	300	8	5	57.17	6.45	2.34

IV. MULTI-CRITERIA DECISION MAKING METHOD

Multiple-Criterion Decision Making (MCDM) refers to making decisions in the Presence of multiple, usually conflicting criteria. Depending on whether the problem is a selection problem or a design problem, the problems of MCDM can be broadly classified into two categories:

- Multiple Attribute Decision Making (MADM)
- Multiple Objective Decisions Making (MODM)

MODM methods have decision variable values which are determined in a continuous or integer domain with either an infinitive or a large number of choices, the best of which should satisfy the decision maker's constraints and preference priorities

- Genetic Algorithm
- Particle Swarm Optimization
- Ant Colony Algorithm
- Ant Bee Colony Algorithm
- Teaching Learning Based Optimization
- Artificial Neural Network

- Heat Transfer Search Algorithm

MADM methods on the other hand are generally discrete, have a limited number of predetermined alternatives. MADM is an approach of problem solving that is employed to solve problems involving selection from among a finite number of alternatives.

- Simple Additive Weighting (SAW) method(Mac Crimon, 1968)
- Analytic Hierarchy Process (AHP) method(Saaty, 1980)
- Technique for Ordering Preference by Similarity to Ideal Solution (TOPSIS) method(Hwang & Yoon, 1981)
- Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) method(Hwang & Yoon, 1981)
- Grey Relational Analysis (GRA) proposed by Deng (1989)
- Elimination and Choice Expressing Reality (ELECTRE) method(Roy, 1991)
- Complex Proportional Assessment (COPRAS) method
- Additive Ratio Assessment (ARAS) method(Zavadskas & Turskis , 2010)
- Multi-Objective Optimization on the basis of Ratio Analysis (MOORA) method

General Structure of Methodology for AWJM Process Parameters Selection Using MADM method

In order to solve the AWJM Process Parameters Selection problems and rank the Process parameters alternatives, integrated AHP-MOORA model is proposed. The general structure of methodology is given in the Figure 4.1.

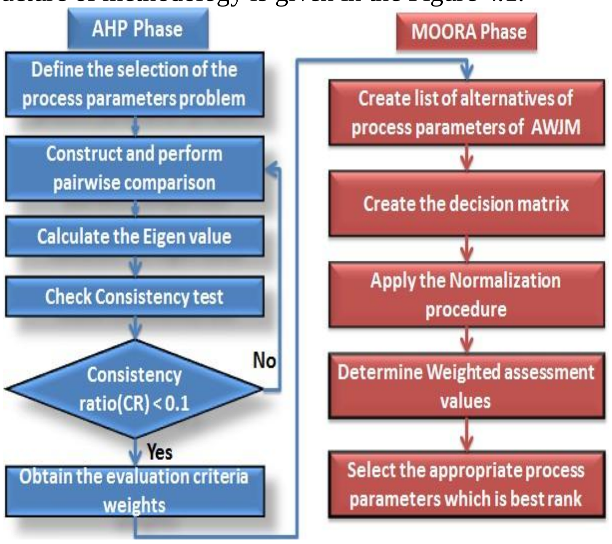


Figure 4.1: General Structure of Methodology

V. RESULT & DISCUSSION

Introduction:

In design of experiment the results are analyzed due to one or more of the following three objectives.

- To establish the best or the optimum condition for a product or a process.
- To estimate the contribution of individual factors.
- To estimate the response under the optimum condition.

The optimum condition is identified by studying the main effects of each of the factors. The main effects indicate the general trends of the influence of the factors. Knowing the characteristics, i.e. whether a higher or lower value produces the preferred results, the level of the factors which are expected to produce the best results can be predicted. The knowledge of the contribution of individual factors is a key to deciding the nature of control to be established on a production process.

Regression

Regression in MINITAB 18 carried out for mathematical modelling of experimental data.

Regression Equation for MRR

MRR = exp(Y')

Y' = 4.312 - 0.001358 TS - 0.0024 AFR - 0.0059 SOD

Link function	Natural log
Rows used	27

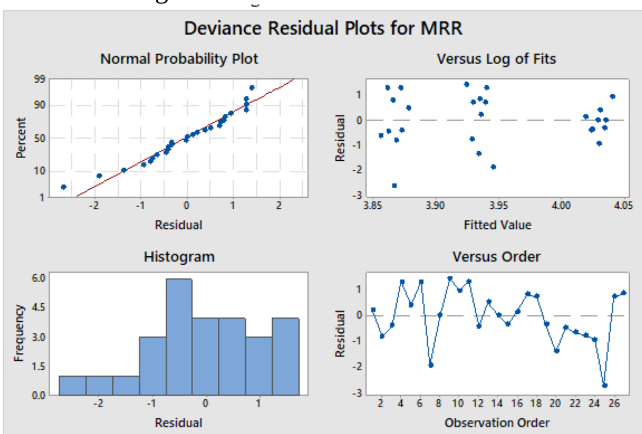
Deviance Table

Source	DF	Adj Dev	Adj Mean	Chi-Square	P-Value
Regression	3	6.3391	2.11305	6.34	0.096
TS	1	6.2853	6.28532	6.29	0.012
AFR	1	0.0216	0.02156	0.02	0.883
SOD	1	0.0323	0.03226	0.03	0.857
Error	23	26.8264	1.16636		
Total	26	33.1655			

Model Summary

Deviance R-Sq	Deviance R-Sq(adj)
86.60%	80.89%

Figure 5.1: Residual Plots for MRR



Here R-square value of modeling is 86.60 % it means that mathematical modeling derived is 86.60 % agree with experimentation results.

Regression Equation for SR

SR = exp(Y')

Y' = 1.282 + 0.00155 TS + 0.0005 AFR + 0.010 SOD

Coefficients

Term	Coef	SE Coef	VIF
Constant	1.282	0.657	
TS	0.00155	0.00168	1.00
AFR	0.0005	0.0502	1.00
SOD	0.010	0.100	1.00

Link function Natural log

Rows used 27

Deviance Table

Source	DF	Adj Dev	Adj Mean	Chi-Square	P-Value
Regression	3	0.86685	0.288950	0.87	0.833
TS	1	0.85587	0.855869	0.86	0.355
AFR	1	0.00008	0.000082	0.00	0.993
SOD	1	0.01090	0.010900	0.01	0.917
Error	23	4.16396	0.181042		
Total	26	5.03081			

Model Summary

Deviance R-Sq	Deviance R-Sq(adj)
87.50%	83.34%

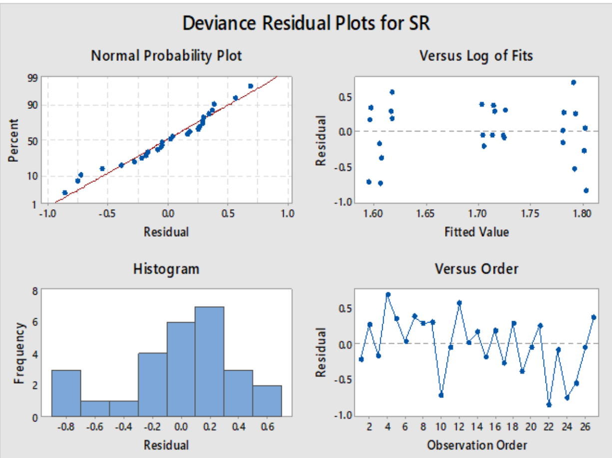


Figure 5.2: Residual Plots for Surface Roughness

Here R-square value of modeling is 87.50 % it means that mathematical modeling derived is 87.50 % agree with experimentation results.

Regression Equation for KW

KW = exp(Y')

Y' = 1.587 - 0.00120 TS - 0.0048 AFR - 0.102 SOD

Coefficients

Term	Coef	SE Coef	VIF
Constant	1.587	0.979	
TS	-0.00120	0.00253	1.00
AFR	-0.0048	0.0765	1.00
SOD	-0.102	0.153	1.00

Link function Natural log

Rows used 27

Deviance Table

Source	DF	Adj Dev	Adj Mean	Chi-Square	P-Value
Regression	3	0.67129	0.223764	0.67	0.880
TS	1	0.22572	0.225720	0.23	0.635
AFR	1	0.00394	0.003938	0.00	0.950
SOD	1	0.44163	0.441633	0.44	0.506
Error	23	4.86193	0.211388		
Total	26	5.53322			

Model Summary

Deviance R-Sq	Deviance R-Sq(adj)
69.03%	37.42%

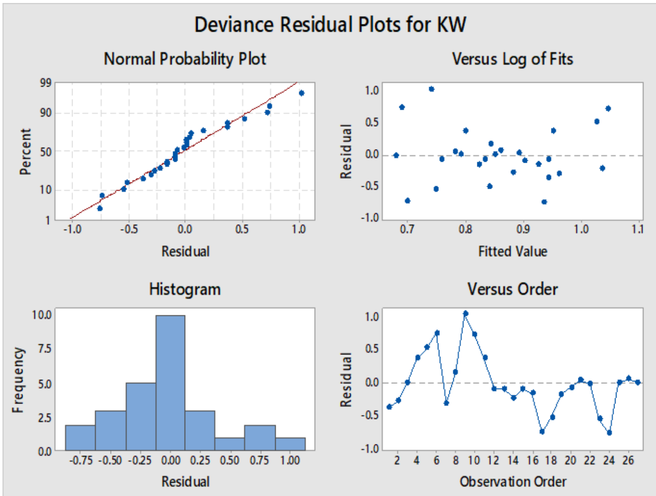


Figure 5.3: Residual Plots for Kerf Width

Here R-square value of modeling is 69.03% it means that mathematical modeling derived is 69.03% agree with experimentation results.

V. CONCLUSIONS

In this paper we studies, the effect of process variables on the response characteristics like material removal rate, surface roughness, kerf width on the Abrasive water jet machining. Experiment based on Full factorial's L27 orthogonal array approach has been conducted on Al 5083 material. The optimization of process parameter using Analytic Hierarchy Process/Multi-Objective Optimization on the basis of Ratio Analysis method and TOPSIS method.

- It is found that stand off distance is most significant parameter in material removal rate. It is conclude that if stand off distance increased than material removal rate decreased. And if stand off distance decreased than material removal rate increased.
- It is found that the MOORA method is simple in calculation, easy to understand and there is no single uncertain parameter for solving AWJM process parameter.

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