

Modeling of Abrasive Water Suspension Jet cutting process using Response Surface Method

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Abstract.

In the paper the influence of following cutting parameters: abrasive flow rate, working nozzle diameter and length on the aluminum cutting depth by Abrasive Water Suspension Jet (AWSJ) was presented. A high efficiency in the aluminum cutting results from the use of circular motion of the liquid to generate an abrasive water jet. This has become possible due to the special mixer in which the water and abrasive mixture is generated directly under high pressure. The research determined the best dimensions of the working nozzle and level of abrasive flow rate to achieve the biggest cutting depth were achieved.

Introduction

Abrasive water jet cutting is one of the quick developing advanced technologies of material separation. It good competes with common methods of cutting, mainly due to widespread nature, resulting in the ample cutting possibilities of both miscellaneous materials, as well as cutting unlimited shapes and work it in extremely dangerous surroundings (hazard of explosion, fire etc.) and environmental friendliness.

In AWJ systems for cutting with 400 - 600 MPa pressure, the injector-mixer is used for the generation of the jet. It is a poor efficiency device, especially when there is a large disparity in the velocities of mixed media. The injector-mixer removal of and the use of circular flow sluicing to mix the pre-formed abrasive and water directly under high pressure allows for higher efficiency of mixing process.

The abrasive cutting process effects are specified by the phenomena taking place in the abrasive grain contact zones with the target material. Studying these phenomena in real conditions is very difficult or even impossible. Accordingly, other modern methods, such as computer numerical simulations and, of course, modeling using statistical-mathematical methods are using.

Abrasive material

Quartz is a mineral consisting of silicon and oxygen. It is silicon dioxide (SiO₂). Quartz is the most frequent mineral found at Earth's surface. It crystallizes in the trigonal crystal system. The perfect shape of this crystal is a six-sided prism ending with six-sided pyramids at each end.

In the AWSJ system, quartz sand is often used as the abrasives mainly due to its low price and good efficiency. As in the case of other abrasives, using the biggest dimension of grains can achieving the bigger effectivity of the cut. Among the abrasive grains (#60, #46 and #30), the biggest and most effective quartz sand #30 was choose for cutting tests.

Target material

PA4 aluminum alloy was used for cutting. This is a light aluminum alloy, which includes apart from aluminum, 1% of magnesium, 1% of manganese and 1% of silicon. It has a better strength and an corrosion resistance than pure aluminum. As all aluminum alloys, it is characterized by a bright silvery white color. PA4 is very susceptible to cold and hot plastic working. PA4 alloy cannot be effectively cut-off by grinding due to the fact that pores of grinding wheel close and it loses the working quality of the abrasive surface. Thermal cutting is made difficult, too, by a good heat conduction and the creation of hard oxides.

Test set up and test method

The test stand was built on the basis of the prototypical appliance from two pressure vessels and four independent hydraulic branches. Each branch is built of the cut-off valve, a throttle valve, a check valve and a manometer. An overflow valve protects the AWSJ system from damage by overpressure. A hydraulic monitor P26 type is the source of a high pressure. It makes it possible to obtain the 75 MPa pressure at the 75 dm³/min rate of water flow. The abrasive flow rate was set indirectly by measuring the abrasive mass, that flowed through the nozzle into the reservoir in a measured time at various settings of the throttle valve

The cuts were made by directing the abrasive water stream perpendicular to the target and moving at a constant traverse speed. The test samples had the wedge shape in a motive to exactly measuring the depth of the cut. The thickness of samples is selected to prevent of total separation cut of material prevent. This could make it difficult to precisely determine the cutting depth.

The design of experiment (DOE) was used to limit the tests number and to shorten the investigations time. The research was catty out in accordance with the full factorial design. The Response Surface Method (RSM) was utilized with a Box-Behnken model. It counts of 60 experiments.

RSM is a join of statistical and mathematical methods for modeling. It can be used in multi-objective optimization. Further, it take into consideration a connection, between the independent variables of the process and the observed responses.

A polynomial equation of second degree for establishing the regression model value is:

$$y = \beta_0 + \sum_{i=1}^k \beta_i x_i + \sum_{i=1}^k \beta_{ii} x_i^2 \pm \varepsilon$$

where:

- y is the dependent variable (response);
x_i indicates values of the i-th cutting parameter,
β₀, β_i, β_{ii} are the coefficients of regressions,
ε is the error acquiring during cutting.

Results and discussion

The influence of input factors (independent variables) on the process result was made through ANOVA (ANalysis Of Variance). The effects of this analysis show the data in Table 3. The analysis was performed for a 95% confidence level (α=0.05). To measure multicollinearity, the variance inflation factor (VIF) was tested. VIF shows how much the variance of an estimated regression coefficient increases if predictors are correlated. For the VIF = 1, there is no multicollinearity. For all inspected factors there no multicollinearity (VIF=1.00) was observed.

On basis of coefficients the terminal cutting depth control model were formulated:

$$D_c = -113.4 + 0.717283 l_N + 91.43 d_N - 0.171 m_a - 0.00589 \cdot l_N^2 - 20.21 d_N^2 - 0.001351 m_a^2 - 0.0066 l_N \cdot d_N + 0.002456 l_N \cdot m_a + 0.1261 d_N \cdot m_a \quad (1)$$

where:

- D_c is cutting depth [mm], l_N is nozzle length [mm], d_N is nozzle ID [mm], m_a is abrasive flow rate [g/s]

Conclusions

This work analyzed the modeling of PA4 aluminum alloy through the RSM for cutting depth. The following conclusions were obtained.

- All tested factors of the AWSJ process have most significant factor on cutting depth.
- The raw data of investigation fit well to the regression line.
- The created mathematical model yield an R² value of over 92%, was accepted to be satisfactory for the cutting depth.
- For all estimated regression coefficient of the model, no multicollinearity was observed (VIF=1.00).
- The optimal settings of AWSJ process parameters observed for in tested area are following: nozzle ID = 2.54 mm, nozzle length = 80 mm and abrasive flow rate = 90 g/s).
- At the above parameters of cutting, the maximum cutting depth of more than 27.8 mm was achieved.

Effects in the work reached with the showed mathematical model and optimal values can be used to production industries, especially where tough conditions protrude and precise cutting profile is necessary.