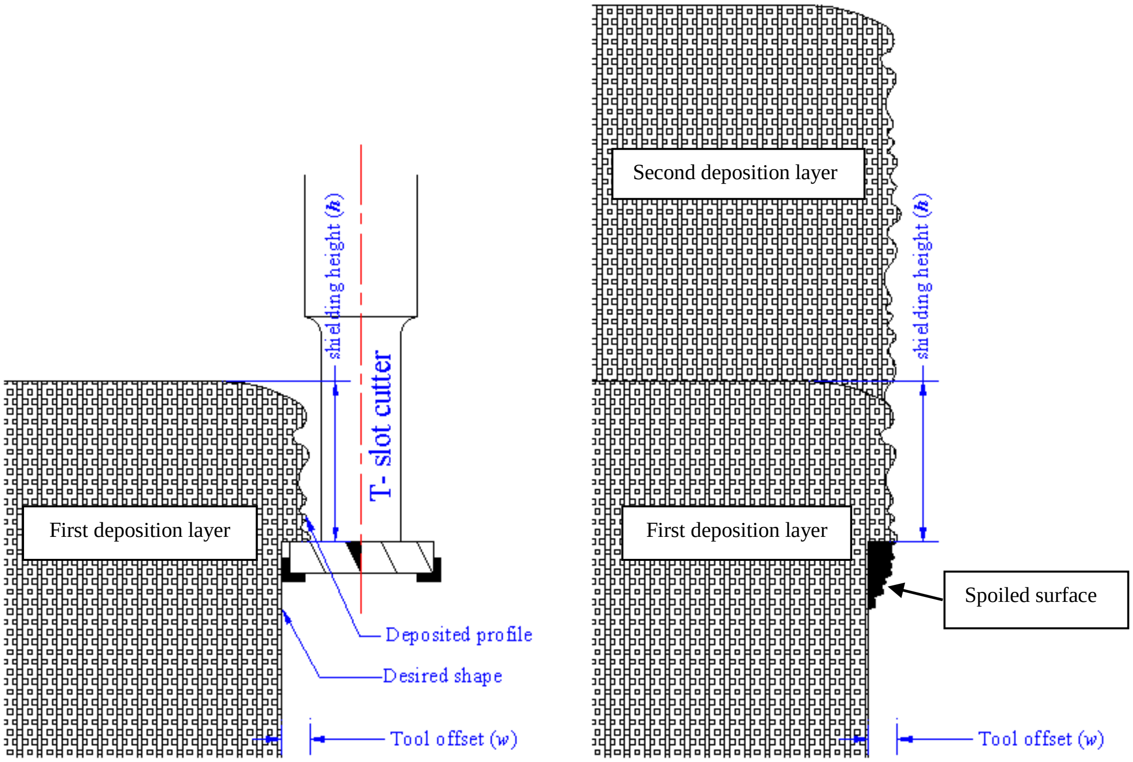
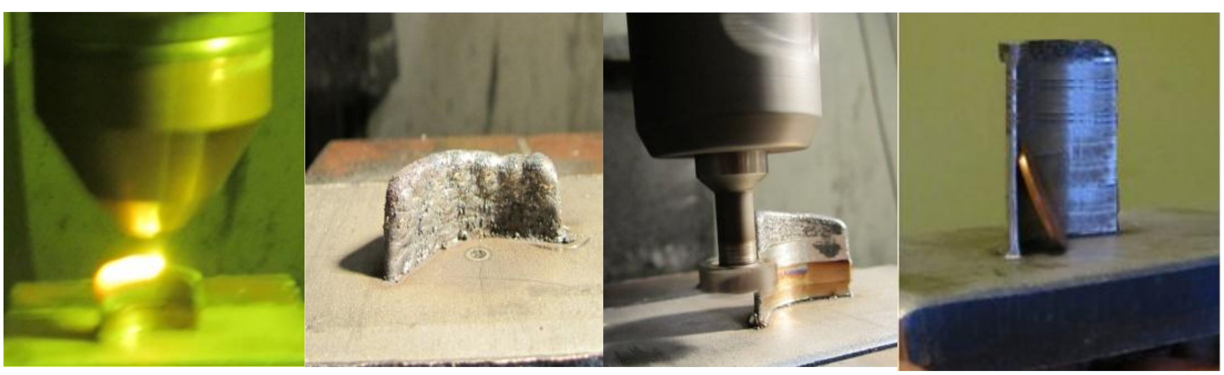


Figure (4): undercut milling machining to reduce spreading of molten pool at the following deposition process

3 Proof of Concept

3.1 Manufacturing

A turbine blade was fabricated by hybrid process combining both a direct metal deposition process and a five-axis CNC milling. It is roughly 30 mm length, 1 mm thick and 50 mm height as shown in figure (5).



(a) (b) (c) (d)

Figure (5): fabricate processes of a turbine blade. (a) laser deposition scene; (b) first layer of laser deposition process;(c) milling process scene; (d) fabricated sample

3.2 Analysis:

The specific problem addressed in this paper is choosing and optimizing the tool offset distance (***w***) and the shielding height distance (***h***) to avoid spreading of molten at the subsequent laser deposition process and to reduce the spoiled surface distance of the previous machined surface profile layer, as shown in figure (4). The spoiled surface distance happen attribute to melt some amount of this overhang which is formed from (***w***) and (***h***). This spoiled surface distance is inversely proportional to (***w***) and (***h***) distances.

In order to maximize the deposition layer thickness "H" to reduce the switching between laser deposition and milling machining processes, there are some conditions should be considered which is listed below:

Conditions of the process:

d_1 : tool diameter
d_2: shank diameter
TL: tool length
h_1: tool width
H: layer deposition thickness
h: shielding height
w : tool offset
$h_1 \leq H - h$
$d_1 - d_2 > w$, illustrated in figure (6).

H_{min}: minimum deposition layer thickness depends on tool width" h_1" .

$$H_{min} \geq h_1 + h$$

H_{max}: maximum deposition layer thickness depends on tool length "TL".

$$H_{max} < h_1 + TL$$

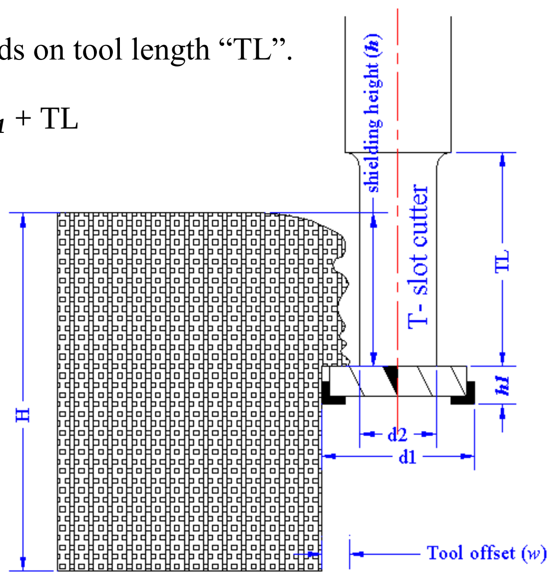


Figure (6): Tool dimensions condition of the process

There are two independent factors: shielding height (***h***) with three levels (1.00, 1.50 and 2.5 mm), and the second independent factor is tool offset (***w***) with three levels (0.40, 0.80 and 1.20 mm). There is one dependent variable which is a non-spoiled machined surface profile height..

Independent variables

Factor A: shielding height (***h***)

Factor A levels (1.00, 1.50 and 2.5 mm)

Factor B: tool offset (***w***)

Factor B levels (0.40, 0.80 and 1.20 mm)

These levels of both factors were selected depend on previous experiments.

Dependent variable: Non-spoiled machined surface profile layer (mm), and it is measured by digital caliper.

The experiments parameters were investigated which are significantly affect the performance characteristics by the ANOVA and the F test (standard analysis) as shown in table (1) and (2).

Table (1): Dependent Variable: non spoiled machined surface

Source	DF	Squares	Mean Square	F Value	Pr > F
Model	8	3.86766667	0.48345833	52.55	<.0001
Error		18		0.16560000	0.00920000
Corrected Total		26		4.03326667	

Table (2):

Source	DF	Squares	Mean Square	F Value	Pr > F
Tool offset	2	1.12186667	0.56093333	60.97	<.0001
Shielding	2	2.66746667	1.33373333	144.97	<.0001
Tool offset*Shielding	4	0.07833333	0.01958333	2.13	0.1191

Both of two factors shielding height (***h***) and tool offset (***w***) are significantly effect on the experiment. With a p-value of 0.1191, the combine if the treatment is not significant as shown in table (2), therefore, the regression model is linear as shown in SAS output in table (3).

Table (3): Parameter Estimate(Parameter Standard)

Variable	DF	Estimate	Error	t Value	Pr > |t|
Intercept	1	9.06111	0.08245	109.90	<.0001
Tool offset	1	0.24667	0.02801	8.81	<.0001
Shielding height	1	0.38000	0.02801	13.57	<.0001

So, our regression model is:

$$Y = \beta_0 + \beta_1 X + \beta_2 X \quad (1)$$

$$Y = 9.061 + 0.246 X_1 + 0.38 X_2 \quad (2)$$

Where, $\beta_{0:}$ intercept of the line. Effects plots, with the regression line, are shown in figure (7).

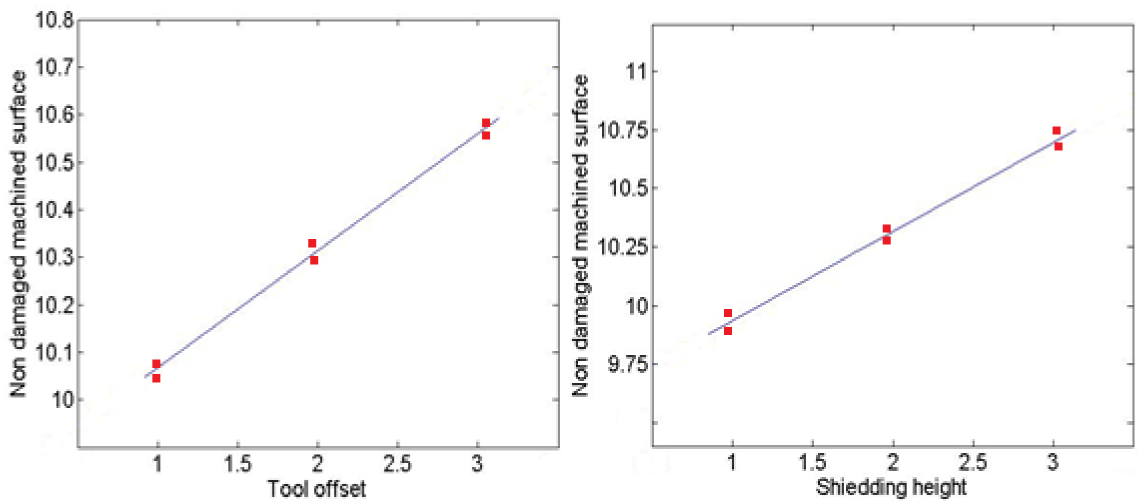


Figure (7): SAS output plot of regression model

With this model the response variable which is non-spoiled machined surface distance (mm) can be estimated clearly.

4 Results and Discussion

The optimization of minimum of both shielding height (***h***) and tool offset (***w***) distances requires the maximum non spoiled machined surface distance is attained. The regression model of experiment is obtained by using SAS software

This work on the development of the DMD process using Hybrid Laser Deposition and Milling (HLDM) technique taking advantage of undercut machining using T-slot cutter to machine laser deposition components to improve surface roughness and dimensions accuracy

To be an efficient solution, both shielding height (*h*) and tool offset (*w*) distances were minimized such that the machined surface was not damaged by subsequent laser metal deposition steps. For the 316L stainless steel used in this experiment, the minimum acceptable value of (*h)* and (*w)* were found to be 1.5 mm and 0.8 mm, respectively, when using 1000 W, 375 mm/min, and 8.0 g/min as the laser deposition parameters. A turbine blade was manufactured using these parameters.

5 Conclusions

Metal Direct Prototyping is unique method among current RP techniques. Hybrid Laser Deposition and Milling (HLDM) can machine complicate shapes that traditional ways cannot do it taking advantage of additive and subtractive technique. Moreover, it is more economy than traditional machining when will be deal with expensive material attribute to some amount of removal material to get the desired shape.

Using this technique, the processing time wasted due to switching between additive and subtractive methods can be minimized. The optimization parameters used here ensure that a minimum amount of material is wasted in the subtractive step. Finally, this method allows for unsupported undercut features to be fabricated via the hybrid process using only 3 axes.

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