Research Article

Build Strategies Based on Substrate Utilization for 3-Axis Hybrid Wire Arc Additive Manufacturing Process

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The hybrid wire arc additive manufacturing (H-WAAM) process is one of the prominent methods for realizing large near-net-shaped metallic objects. In this process, a CAD model of the component is sliced into a set of 2D contours followed by the generation of toolpaths. An arc welding torch then follows these toolpaths for adding material over a substrate to realize the near-net shape of the object. These near-net-shaped objects are then followed by a machining operation to convert them into a fully functional part. It is always anticipated that the near-net shape of an object is produced quickly and upholds a high geometrical accuracy. Conventionally, the deposition rate is increased to reduce the build time but with a compromising in the geometrical accuracy and material integrity. Therefore, in this work, the authors have investigated three substrate utilization methods, viz., (i) reusable substrate, (ii) embedded substrate, and (iii) integrated substrate to achieve the same goal. The build strategies for these three substrate utilization methods are illustrated through several examples. Also, a case study was performed for fabricating an impeller-like structure through a 3-axis H-WAAM setup. It has been observed that the embedded substrate method exhibits superior geometrical accuracy and takes less time to build the part as compared to other methods. A maximum of 64.34% of the material and 89.17% of build time is saved by adopting proposed build strategies compared with the traditional subtractive process.

1. Introduction

The wire arc additive manufacturing (WAAM) process is preferred over other metal additive manufacturing (AM) processes to realize larger metallic objects with a shorter built time [1]. WAAM setups consist of two main modules: (a) deposition module and (b) motion module. The former is responsible for the deposition process, while the latter controls the movement of the deposition head to disperse material selectively over the sliced region. Based on the motion unit, WAAM setups are broadly classified into two categories: CNC-based WAAM and robotic WAAM (R-WAAM), as shown in Figure 1. In the case of CNC-based WAAM, the motion is manipulated with the help of a CNC controller. In most cases, the repeatability and accuracy of these machines are much higher. On the other hand, R-WAAM setups have the advantage of a larger work envelope and multidirectional deposition capability at the cost of relatively poor accuracy. If the subtractive machining module is incorporated with the CNC-based WAAM, the process is termed as H-WAAM. Current researchers are observed to be more inclined towards a GMAW-based WAAM setup with different degrees of freedom due to its ease of control [2–20]. The precise control over the bead and stable arc often gave GTAW-based WAAM an edge over other WAAM setups [21–33]. However, the omnidirectionality issue restricts its application in robotic cells without an external wire feeding unit. Therefore, the limited literature has been found in GTAW-based WAAM setups [29–33]. Owing to the same reason, works utilizing PAW-based WAAM setup are also minimal [34–39].

WAAM utilizes an electric arc to melt the feedstock wire and deposit selectively over the prebuilt layer/substrate. Veiga et al. tried to minimize the wastage of material in this process by topologically optimizing the component [40]. It was reported to reduce material wastage by 31% by adopting...
the proposed algorithm. Similarly, Ramonell and Chacón performed topology optimization in eccentrically braced frames fabricated through WAAM [41]. Abe and Sasahara also proposed lattice structures with the same strength for minimizing wastage of materials using WAAM [42].

The substrate that acts as the support to the first layer is often required to remove from the final fabricated component. This enhances the wastage of material, leading to an increase in the cost of production. Moreover, higher heat input of the process often results in a geometrical disparity of the fabricated part from the desired dimensions [3]. Such issues of the process can be overcome by optimally using the substrate. Few researchers are involved in studying the effect of substrate utilization for AM technologies. In most cases, the emphasis is made on optimizing the build orientation of the component so that the minimum support structures can be provided for undercut features [43–46]. However, build strategies based on substrate utilization for WAAM should be considered different from that of other AM processes due to the higher deposition rate and heat input. The study on the effect of different possible methods for substrate utilization in WAAM still remains unexplored. A substantial amount of materials can be saved during WAAM through optimal substrate utilization. Williams et al. [47] can be identified as one of the initial research groups to coin the idea of different methods for utilization of substrate in WAAM. They have recognized different challenges associated with components fabricated through WAAM. It has also been proposed that the residual stress that occurs due to high heat input can be mitigated through proper build strategies. The symmetrical building and back-to-back buildings are reported to be efficient methods for mitigating residual stresses. However, a detailed study of the strategies is not carried out in their work. The same work has been further extended by Lockett et al. [48]. They have used a similar build strategy based on substrate utilization in WAAM. A model has been developed for optimizing the cost of the component. However, they have not experimentally demonstrated the strategies.

From the literature survey, it has been observed that few research groups have studied the effect of substrate utilization method in WAAM fabricated components. To the best of the author’s knowledge, no one has systematically explored the substrate utilization method for 3-axis H-WAAM setup experimentally. In this work, three different methods for utilizing the substrate in H-WAAM have been investigated. An illustrative case study has been performed to implement the proposed methods. A comparative study of the proposed strategies has been carried out in detail.

2. Research Background

WAAM exhibits better material efficiency (less material waste) as compared to the traditional manufacturing processes [49]. This can be further enhanced with a suitable substrate utilization method. In this work, three different methods for utilizing the substrate in H-WAAM have been developed, as shown in Figure 2. The waste portion of the substrate is represented by the grey colour. The layers that would be embedded inside the substrate are shown by a green-coloured dotted box. The proposed methods can be implemented into a 3-axis H-WAAM setup. The advantages and challenges in each method, along with the process flow chart, have been discussed in the subsequent section.

2.1. Reuable Substrate. In this strategy, the same metallic substrate is utilized again and again for different components. This is the most popularly used build strategy in WAAM [11, 50, 51]. The feedstock material for the initial layer is deposited over the substrate, as shown in Figure 2.
The subsequent layers are realized over the prebuilt layers. Once the entire component has been realized, the component is parted off from the substrate [52–56]. The use of sophisticated machine tools such as wire cut will lead to a good surface finish; however, the overall built time will be increased.

2.2. Embedded Substrate. The high deposition rate of the GMAW-based H-WAAM process often results in a poor surface finish [11]. Therefore, it sometimes becomes essential to perform post-machining operations to achieve the desired level of surface finish. This results in a significant increase in the manufacturing build time. However, in the case of certain components, the deposition of certain subvolumes of primitive shapes can be avoided using the substrate of the same shape and dimensions as that of the subvolume. The number of layers embedded into the subvolume is governed by the slice thickness. These layers are represented by a green dotted line in Figure 2. Hence, the time required to deposit the subvolume and separate it from the substrate can be eliminated. This method improves dimensional accuracy and the properties of the final component. The built time of the component can also be minimized. Moreover, certain overhang features can be avoided by adopting this strategy. The layers represented by red colour are deposited by flipping the substrate. There are various algorithms available in the literature for feature-based volume decomposition of CAD models [57–59]. These algorithms can be easily implemented to identify the volume suitable for the substrate. In this work, an algorithm, as shown in Figure 3, has been proposed to evaluate the optimal position of the substrate.

2.2.1. One-Side Deposition. Based on the position of the substrate, the deposition may be carried out on either both or a single side of the substrate. The substrate may be embedded into the final component. If the optimal position of the substrate is found to be in the bottom of the component along the build direction, a one-side deposition strategy will be required to be followed. Figure 4(a) depicts the setup used for a one-side deposition strategy. A similar setup can be used for the reusable substrate method as well.

2.2.2. Both-Side Deposition. If the position of the substrate is found to be at an intermediate location of the component, then a both-side deposition strategy is required to be followed. The substrate may be flipped by 180° after the completion of deposition on one side. This flipping process can be carried out using an indexing fixture, as shown in Figure 4. It can also be flipped manually if jigs are provided in the substrate to coincide with the work coordinate system (WCS) precisely.
2.3. Integrated Substrate Method. The high heat input in the case of WAAM often leads to distortion of the components due to thermal stress [60]. The residual stress resulting from thermal cycles upshots warpage of the substrate. This not only affects the component dimensional accuracy but also makes the substrate unusable after fabricating a few components. This escalates the volume of sacrificial materials by incorporating the mass of the substrate. Hence, the reusable substrate method is limited by the volume of productions. In this strategy, two components can be deposited simultaneously on both sides of the substrate. The distortion of the substrate resulting from deposition on one side will be balanced by the other side. Moreover, this strategy will improve the production time by eliminating substrate setting time for the second component. A common WCS helps in generating toolpaths for both the components in a single NC file. The same indexed substrate clamping fixture as shown in Figure 4(b) can be utilized for this strategy. Since the warpage of the substrate is restricted in this method, the same substrate can be utilized for multiple components. This helps in approaching the sustainability of the manufacturing process by reducing the volume of sacrificial material. Similar to the embedded substrate method, two different slicing planes are calculated on both sides of the substrate.

2.4. Hybrid Substrate Method. There are certain components in which the optimal position of substrate lies at the bottom of the component. Productivity for such components can be enhanced by hybridizing embedded and integrated substrate
methods, as shown in Figure 2. This helps in attaining beneficial features of both strategies. The substrate may be prepared according to the final shape of the component with a thickness of twice as required. Hence, intricate shapes can be deposited on both sides of the substrate. Finally, two similar components can be yielded by splitting the substrate through the central symmetry plane. This will also reduce the amount of sacrificial material. Similar to the embedded substrate method, the substrate cannot be reused as it is embedded into the final fabricated component.

3. Materials and Methods

Figure 5 illustrates the flow chart for choosing an ideal method for substrate utilization. The process starts with importing the CAD model. If the user prefers to reuse the substrate for different components, then there will be two options available for substrate utilization. In the case of the first method, the component may be deposited along one direction above the substrate following the reusable substrate method. If it is required to realize more than one component, then the user can choose the integrated substrate method in which two components may be realized on both sides of the substrate. The second method improves the productivity and reusability of the substrate. Contrary to this, in the case of the nonreusable substrate method, the optimal position of the substrate may be found within the component using algorithm 1, as shown in Figure 3. Hence, the layers embedded into the substrate can be eliminated during deposition leading to the minimization of a substantial amount of material waste and built time. Similar to the integrated substrate method, the productivity of this method can also be improved by hybridizing the integrated substrate method and the embedded substrate method. This helps in attaining beneficial features of both methods. The bottom layers of the component will be embedded into the substrate. The built time and volume of sacrificial materials can be reduced significantly by adopting this method.

3.1. The Optimal Position of the Embedded Substrate. To implement the embedded substrate method, it is essential to evaluate the optimal position of the substrate within the component. In the case of symmetric objects, the optimal location of the substrate is generally found to be along the plane of symmetry. However, four generalized constraints need to be satisfied to calculate the optimal position of the substrate. These are determined based on the minimization of built time and wastage of materials. Constraint I helps in performing machining with the least number of part setups in the machine bed. This results in a decrease in built time by eliminating unnecessary setting time. Constraint II enhances the surface quality of the fabricated part. It minimizes the wastage of sacrificial materials. Moreover, the machining time that would require to remove the support structures can also be eliminated. Constraint III aids in minimizing warpage leading to minimum distortion in the final part. This helps in reducing machining allowances resulting in less wastage of materials. Constraint IV results in minimizing the wastage of material by embedding a maximum portion of the substrate into the final component. This also helps in eliminating the time required to realize the layers embedded inside the substrate.

Constraint 1: machining operation should be done efficiently.

Constraint 2: the object should be deposited without any support material.

For an object A, which is required to be deposited over substrate B, of n numbers of possible orientations, the ith orientation about the global coordinate system is represented by equation (1). $R(R_{x}, R_{y}, R_{z})$ characterizes rotation vector of the component for $R_{x}$, $R_{y}$, and $R_{z}$, which signifies rotation of the component about $x$, $y$, and $z$ axis, respectively.

$$O_{i} = (0, 0, 0, R_{x}, R_{y}, R_{z}).$$

(1)

The dimensions of the bounding box of the object in ith orientation as shown in Figure 6 are as follows: $X_{max} \times Y_{max} \times Z_{max}$, and then, the dimension of the substrate B in this orientation ($DS_{i}$) can be given as follows:

$$DS_{i} = (X_{max} + 2 \times a) \times (Y_{max} + 2 \times b) \times t,$$

(2)

where $t$ is the thickness of the substrate and $a$ and $b$ are the fixture allowances in X and Y directions, respectively. In the ith orientation, the total number of possible positions of the substrate is $m_{i}$. The jth position of the substrate can be represented by $P_{ij}$.

$$P_{ij} = (0, 0, Z_{ij}, 0, 0, 0).$$

(3)

Constraint 3: the position of the embedded substrate should be near to plane of symmetry (assuming $Z = 0$ at the plane of symmetry). Therefore, the optimal position of the substrate in ith orientation is given as follows:

$$P_{o} = \frac{P_{ij}}{P_{ij}} \min \left(\left|P_{ij}\right|\right).$$

(4)

Constraint 4: the intersecting volume between the substrate and component should be maximum.

The volume of intersection ($VI_{i}$) between the object in ith orientation and substrate at position $P_{0}$ can be evaluated using the following:

$$VI_{i} = \text{volume of } (A(O_{i})) \cap (B(P_{0})).$$

(5)

The algorithm for the calculation of the optimal position of the substrate is illustrated in Figure 3. It can be implemented in any CAD/CAM system. Slicing can be done after locating the position of the substrate. During planar slicing of the embedded substrate method, the slicing plane moves in both directions of the substrate.

3.2. Illustrative Examples. The investigated substrate utilization methods are illustrated with different examples.
Figure 5: Flow chart for choosing the ideal substrate utilization method.

Figure 6: Orientation of the object and position of the substrate.
During the reusable substrate method, the first layer is realized over the substrate. As shown in Figure 7(a), the object will require support for the undercut regions. To eliminate the requirement of support, an embedded substrate method can be adopted. The optimal position of the substrate for the embedded method, for example 1, is found to be \((0, 0, 90°, 0°, 0°)\). Figure 7(b) shows the variation of volume of intersection (VI) with different positions of the substrate. For clarity of the image, only three primary orientations of the CAD model are illustrated. Similarly, in the case of example 5, as shown in Figure 8(b), the maximum VI is found to be with orientation \(R(0, 90, 0)\). However, the second constraint regarding support structure is being violated. Hence, the optimal position for realizing the component can be considered to be \(O (0, 52, 90°, 0°, 0°)\). For a better understanding of algorithm 1, the method has been demonstrated for different CAD models as shown in Figures 7 to 12. The optimal position of the substrate in each model has been represented with the help of the corresponding VI curve.

3.3. Experimental Setup. The proposed build strategies are validated in an in-house developed CNC-based WAAM setup. An existing 3-axis CNC milling machine has been retrofitted with a GMAW machine, as shown in Figure 13. The CNC machine is having a Siemens SINUMERIC 808D controller, while the deposition module is Fronius-made TransSteel 2200. The synergic integration between the two
Figure 9: Illustrative example 2: (a) CAD model and (b) VI for different positions of the substrate with different orientations.

Figure 10: Illustrative example 3: (a) CAD model and (b) VI for different positions of the substrate with different orientations.

Figure 11: Illustrative example 4: (a) CAD model and (b) VI for different positions of the substrate with different orientations.
modules has been achieved through proper PLC coding. The schematic diagram of the setup is shown in Figure 13. The detailed process of retrofitment can be found in the literature [21]. The process parameters can be optimized by performing a single bead experiment; however, this optimization is out of scope of this work. The optimized process parameters maintained throughout the experiments are listed in Table 1 [61]. The optimized parameters are considered for the milling process [62].

3.4. Case Study. The proposed build strategies are illustrated by fabricating a mild steel impeller, as shown in Figure 14. Since the objective of this work is to study the effect of different substrate utilization methods, the model is scaled down to (1/4)th of the actual model to save resources used for deposition. The impeller has been deposited over a mild steel substrate. Zigzag toolpath was chosen for area filling in each strategy. The other parameters used for deposition are listed in Table 1. The detailed process for each strategy has been elaborated in the subsequent section.

A mild steel substrate of 80 mm × 80 mm has been chosen for the reusable substrate method. As shown in Figure 15, the process planning of the reusable substrate method starts with the optimal orientation of the component. The optimality can be checked by identifying an orientation with no overhang feature. Once the object is

Table 1: Set values of process parameters.

| Parameters              | Value            |
|-------------------------|------------------|
| Current                 | 120 A            |
| Wire feed speed         | 8.3 m/min        |
| Standoff distance       | 12 mm            |
| Shielding gas flow      | 10 L/min         |
| Shield gas type         | Argon-CO₂ mixture (80%–20%) |
| Deposition speed        | 800 mm/min       |
| Filler wire diameter    | 0.8 mm           |
| Filler wire             | ER70S-6          |
Figure 14: CAD model of the impeller.

Figure 15: Process flow for reusable substrate method.
oriented optimally over the substrate, the slicing plane has been generated on top of it. Planar slicing of the component has been performed due to kinematic restrictions of 3-axis machines.

The slices at each slicing plane have been evaluated. Machining allowance has been provided to the contours obtained after slicing. The toolpaths for the offset contours of each slice have been calculated. Figures 16 and 17 depict slices and corresponding toolpaths for deposition, respectively. The final fabricated component is shown in Figure 18. It has been removed from the substrate using wire-cut EDM.

In the case of the embedded substrate method, the optimal position of the substrate is required to be evaluated. The same orientation requires no support structure to realize in the $+Z$ direction. The variation $VI$ to the different orientations of the model is evaluated. For simplicity, $VI$ for five build directions is shown in Figure 20. From the figure, it can be concluded that the optimal position of the substrate is $(O, 0, 0, 0°, 0°, 0°)$. The base of the impeller, as shown in Figure 21, can be manufactured in a lathe/milling machine. The remaining intricate subvolume, i.e., blades, can be realized through the H-WAAM process. The dimensional accuracy, as well as the properties of the final component, can be improved with this substrate utilization method as the subvolume, which acts as the substrate, is already prepared as per the required dimensions and surface roughness value.

There are numerous algorithms for feature-based volume decomposition of CAD models available in the literature [57–59]. These algorithms can be easily implemented to identify suitable shapes for the substrate. The process flow of the embedded substrate strategy is shown in Figure 22. Similar to the reusable substrate method, the slicing plane is generated at the top of the substrate with the help of the bounding box of the component. Figure 23 depicts the slices of the impeller with the embedded substrate method. Toolpath for area filling has been evaluated for each slice, as shown in Figure 24. The near-net shape of the component is exhibited in Figure 25.

The abovementioned strategies are generally used for the realization of a single component in a given substrate. The productivity of the process can be improved by adopting the integrated substrate method. In this strategy, two components on both sides of the substrate are deposited. The process flow for this strategy is similar to that of the reusable substrate method. The flow chart is shown in Figure 26. Similar to the reusable substrate method, slicing planes are generated on both sides of the substrate after the evaluation of optimal build orientation. The slices of the impeller on both sides have been computed, as shown in Figure 27. The substrate has been flipped after deposition on one side. The toolpath for the slices is shown in Figure 28. Both the impellers are separated from the substrate using wire-cut EDM. The near-net shape obtained after deposition is shown in Figure 29.

The built time can be further improved by utilizing hybridization of the integrated substrate method with the embedded substrate method. Since the optimal position of the substrate in the case of the embedded substrate method is found to be along the base of the impeller, therefore, the substrate can be prepared as per the dimension of the base of the impeller. The thickness of the substrate can be considered to be twice that of the impeller base. The blades can be deposited on both sides of the impeller. Finally, two impellers can be yielded by splitting the substrate along the central symmetry plane. The process flow is illustrated in Figure 30.

4. Result and Discussion

The deposited impellers with different substrate utilization methods are converted into digital models using a laser 3D scanner. The scanned models are then compared with the CAD model of the near-net shape of the impeller. The dimensional disparity is evaluated using the open-source software CloudCompare [63]. The software’s algorithm reads two STL files and converts one of the models into point clouds. The nearest Euclidean distance between the points in the compared and reference model is evaluated using the following:

$$d(a, b) = \sqrt{\sum_{i=1}^{n} (a_i - b_i)^2},$$

Figure 16: Slices of the impeller with reusable substrate method.

Figure 17: Toolpaths for the deposition of the impeller with reusable substrate method.
where \( d(a, b) \) represents the Euclidian distance between measured point cloud \( a \) and reference point cloud \( b \). The software is validated by computing the disparity between actual CAD and near-net-shaped CAD models obtained by extruding the slices with machining allowance. As shown in Figure 31, the mean distance is found to be 0.968 mm. This matches the given 1 mm of machining allowance with a 3.3% of error. The mean distance between the CAD model of near-net shape and the impeller realized through the reusable substrate method is evaluated to be 0.967 mm, as shown in Figure 32. The variation of distance for different points in the digital model of the impeller realized through the embedded substrate method is shown in Figure 33. The least mean deviation of 0.479 mm was observed in the case of the embedded substrate method in comparison with other models. This is due to the fact that the base of the impeller is prepared by a conventional manufacturing process with required dimensional accuracy. Similarly, Figure 34 depicts the variation of distance of the scanned model of the integrated substrate method. The highest deviation is observed to be 8.12 mm. This occurs because of the higher deposition rate of WAAM. Most of the points are observed to be deviated by 1.129 mm. Table 2 shows the mean disparity of deposited models from the near-net-shaped CAD model. The surface roughness can be further improved by performing finish milling; however, it will have a similar effect in the components realized through each substrate utilization method.

The volume of the fabricated components is exhibited in Table 3. It is found to be almost similar for all the models. The volume of a cylindrical block (80 mm \( \times \) 30 mm) that would be required to manufacture the impeller by the subtractive process is 150796 mm\(^3\). Therefore, a maximum of 64.34% of materials can be saved through the embedded
**Figure 22:** Process flow for embedded substrate method.

**Figure 23:** Slices of the impeller with embedded substrate build strategy.

**Figure 24:** Toolpath for the deposition of the impeller blades with embedded substrate method.
Figure 25: Near-net shape of the impeller realized through embedded substrate method.

Figure 26: Process flow for integrated substrate.
Figure 27: Slices of integrated substrate build strategy.

Figure 28: Toolpath for integrated substrate build strategy.

Figure 29: Near-net shape of the impellers deposited with integrated substrate method.
substrate method as opposed to the purely subtractive process. Similarly, 61.35% and 64.29% of material waste can be avoided through reusable and integrated substrate methods, respectively, as compared to the traditional subtractive process.

Table 4 shows the time required to realize the components. The least built time is observed in the case of components realized through the embedded substrate method. This is because only blades are being deposited. The substrate is already prepared as per final requirements. The integrated substrate method requires maximum time because two components are being fabricated simultaneously. An interlayer cooling time of 120 s is provided before deposition of the subsequent layer. After the deposition of each layer, intermediate facing is performed with 0.5 mm depth of cut to maintain 2 height accuracy. The zigzag strategy is used for
**Figure 32:** Cloud-to-mesh distance of near-net-shaped CAD model and scanned model of component realized through reusable substrate method.

**Figure 33:** Cloud-to-mesh distance of near-net-shaped CAD model and scanned model of component realized through embedded substrate method.

**Figure 34:** Cloud-to-mesh distance of near-net-shaped CAD model and scanned model of component realized through integrated substrate method.
the deposition and facing process. The overall built time is evaluated by summing up deposition time, facing time, and interlayer cooling period. The subtractive toolpath has been calculated to realize the near-net shape of the impeller from a cylindrical stock of size of $\phi 80 \text{mm} \times 30 \text{mm}$. It has been observed that 71.16% and 89.17% of the built time can be reduced with reusable substrate and embedded substrate methods, respectively, in comparison with the purely subtractive processes. However, the time required for substrate preparation and removal is not considered as it will have a similar effect in all the methods.

The computational cost is more in case of the embedded substrate method in comparison with the integrated substrate and reusable substrate methods due to multiple iterations involved in algorithm 1. However, this increase in cost is justified due to a significant reduction in deposition time and fabrication cost. Moreover, the manufacturing cost can be further reduced due to a substantial reduction in machine hour as compared to the traditional subtractive process. The cost of the tool can also be reduced in case of proposed methods as compared to the traditional process. Likewise, a fair amount of manufacturing cost can be saved in case of the embedded substrate method as compared to the subtractive process in terms of raw materials.

### 5. Conclusion

In this work, three substrate utilization strategies for 3-axis H-WAAM have been investigated. The reusable substrate strategy has been observed to be adopted in most of the applications. The embedded substrate method exhibited the least geometrical discrepancy and built time. This is because the substrate is embedded with the final component. The algorithm for evaluating the optimal position of the substrate within the component has been developed. The integrated substrate method provides better productivity and
helps in realizing two components simultaneously over the same substrate. A hybrid strategy combining the embedded substrate method with the integrated substrate method will further improve the dimensional accuracy, built time, and productivity of the process. Table 5 represents a comparison among the proposed methods. A mild steel impeller has been fabricated as a case study. A maximum of 64.34% of the material and 89.17% of the built time can be saved using the embedded substrate method in comparison with the traditional subtractive process for realizing the mild steel impeller. These substrate utilization methods can be further extended for depositions involving higher kinematics. The efficiency of the methods can be enhanced by utilizing curved substrates. However, a detailed study is required to implement the investigated substrate utilization methods in a nonplanar substrate.

Data Availability
The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest
The authors declare that they have no conflicts of interest.

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