the peening or rolling tools. They also can increase the time and complexity for manufacturing a workpiece, and thus can be overly costly or impractical to utilize.

[0010] These methods also can increase waiting times between layers, which can negatively affect productivity and potentially limit fabrication freedom. Excessive cooling between layer deposition also can increase the temperature differential between layers and further exacerbate residual stress development. For the methods that physically work the deposited layer, contaminations from tooling also will be a concern since any contaminations can get enclosed between layers of the final product in an additive process.

[0011] Accordingly, there exists a need in this art for an economical method of performing direct metal deposition at a rate of metal deposition in an additive manufacturing system that yields metal products having reduced or minimized residual stress, or distortion, or both, than is achieved in traditional additive manufacturing processes. It would be desirable to provide DED processes that reduce the incidence of residual stresses or cracking in the DED manufactured object. It also would be desirable to provide DED processes that reduce the incidence of local distortion of the object being manufactured as additional metal layers are deposited.

Summary

[0011a] In an aspect, the present disclosure refers to a curved clamping mold for mitigating distortion in metal objects manufactured using a directed energy deposition additive manufacturing process, wherein the curved clamping mold is used as a support between a pre-bent substrate and a jig in the manufacturing process, the curved clamping mold comprising: a first side comprising: two or more cavities separated by one or more stiffening member; and a rim having a flat surface around a perimeter of the first side; a second side opposite of the first side, the second side having a curved surface and comprising knurls or corrugations; and a ceramic coating disposed on the knurls or corrugations, wherein the curved clamping mold comprises a metal having a melting point of 1350ºC or greater.

[0011b] In another aspect, the present disclosure refers to a directed energy deposition method for producing a metal workpiece, comprising: pre-bending a substrate of a metal material with thermal energy by forming a plurality of melting tracks on a first surface of the substrate using a melting tool to produce a pre-bent substrate; using the curved clamping mold of the above aspect to support the pre-bent substrate, and securing the pre-bent substrate and the support structure supporting the pre-bent substrate to a jig using a plurality of clamps; and forming the metal workpiece on a second surface of the substrate by an additive manufacturing process that comprises melting a metal feedstock to deposit a layer of molten metal on the second surface of the substrate to form a base material and deposits subsequent layers of molten metal on the base material to form the workpiece, wherein the second surface of the substrate is opposite the first surface of the substrate.

[0011c] In another aspect, the present disclosure refers to a system for directed energy deposition, comprising: a jig for securing a pre-bent substrate; a curved clamping mold of the above aspect to be positioned between the jig and when the pre-bent substrate is secured to the jig; clamps for securing the pre-bent substrate to the jig; one or more melting tools comprising a DED thermal source to melt a source of metal into metallic molten material that is deposited on a surface of a base material; a gas jet device to direct a cooling gas to impinge upon the as-solidified material adjacent to a liquid-solid boundary of the liquid molten pool to influence temperature gradients; a supply of the cooling gas; and an actuator for positioning and moving the base material relative to the melting tool and the gas jet device.

[0012] Accordingly, examples provided herein are directed to production of workpieces having reduced or minimized residual stress, or distortion, or both using additive manufacturing processes that substantially obviates one or more of the problems due to limitations and disadvantages of the related art. As embodied and broadly described, provided are devices, systems and methods to reduce or minimize residual stress or distortion or both during metal additive manufacturing to achieve products with improved material quality. DED manufactured products having these reductions in residual stress or distortion demonstrate increased strength, fatigue resistance, and durability. The devices, system and methods

provided can increase throughput and yield of DED formed products, and yield workpieces within specified tolerances.

[0013] Because the methods provided herein can reduce or eliminate residual stress or distortion or both, the methods can be used to fabricate DED