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Additive manufacturing - Residual stress of metal parts - Method of sound beam control

增材制造 金属制件残余应力声束控制法

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1 Scope

This document specifies the principle, the operators, the sound beam control system, the working process, the inspection method and the process record documents of the sound beam control method applied to residual stress during the production of metal parts by additive manufacturing.

This document applies to the relief and evening out, by the sound beam control method, of the residual stress arising during the production of aluminium alloy, titanium alloy and hard alloy metal parts by arc additive manufacturing.

2 Normative references

The contents of the following documents constitute indispensable provisions of this document through normative reference in the text. For dated references, only the edition corresponding to that date applies to this document; for undated references, the latest edition (including all amendments) applies to this document.

GB/T 12604.1 Non-destructive testing - Terminology - Ultrasonic testing

GB/T 32073 Non-destructive testing - Test method for residual stress by ultrasonic critically refracted longitudinal wave

GB/T 35351 Additive manufacturing - Terminology

GB/T 38811 Metallic materials - Residual stress - Method of sound beam control

GB/T 38952 Non-destructive testing - Test method for residual stress by ultrasonic bulk wave

GB/T 40121 Technical product documentation - Symbolic representation of residual stress of products

3 Terms and definitions

The terms and definitions given in GB/T 12604.1 and GB/T 35351, together with the following, apply to this document.

3.1 sound beam control. The process of injecting an acoustic wave or elastic wave carrying a certain energy into the interior of a material, in a given direction and within a given range, so that the residual stress inside the material is relieved and evened out to a certain degree.

3.2 timing control. The process of controlling the acoustic energy at different positions in space according to the position and speed at which the various heat sources are formed.

3.3 exciter. A device able to generate a certain energy, in which the frequency and amplitude of the elastic wave are controllable. Note: exciters are usually built on principles such as piezoelectric ceramics. [Source: GB/T 38811-2020, 5.4, modified]

3.4 ultrasonic horn. A component mounted at the end of the exciter and tightly coupled to the reverse side of the working face of the substrate, used for thermal insulation and for the transmission and transformation of the acoustic wave.

3.5 couplant. The medium applied between the end face of the horn and the reverse side of the working face of the substrate, or the surface of the additively manufactured part, to ensure the transfer of the ultrasonic energy.

4 Principle

A sound beam carrying a certain energy and having a certain directivity is transmitted into the interior of the material through the couplant; its energy drives the particles of the material into vibration and alters the microstructure of the material, so that the residual stress in the material is relieved and evened out. The arrangement is shown schematically in Figure 1.

The parts identified in Figure 1 are: 1, deposited layer; 2, welding torch; 3, melt pool; 4, sound beam; 5, couplant; 6, exciter; 7, excitation power supply; 8, horn; 9, substrate.

5 Operators

Operators shall have a basic knowledge of residual stress control and of additive manufacturing processes, and shall be familiar with the operation of the sound beam control system.

6 Sound beam control system

6.1 System configuration. The residual stress sound beam control system is made up of the additive control system, the ultrasonic power controller, the excitation power supply, the exciter, the heat-insulating horn and peripheral equipment (including the clamping device and the excitation voltage transmission cables), with a couplant used as the medium through which the sound beam is transmitted, as shown in Figure 2.

The parts identified in Figure 2 are: 1, additive control system; 2, ultrasonic power controller; 3, excitation power supply; 4, exciter; 5, heat-insulating horn; 6, substrate; 7, additively manufactured component; 8, couplant.

6.2 Ultrasonic power controller. The ultrasonic power controller shall be able to monitor the excitation power supply, to control the workflow of stress control, and to start and stop the system.

6.3 Excitation power supply. The excitation power supply shall be able to generate a power ultrasonic signal that drives the exciter to produce ultrasonic waves, and shall provide feedback signals of the excitation voltage and current so that the state of the ultrasonic wave can be monitored in real time.

6.4 Exciter. The exciter is usually a sandwich piezoelectric ultrasonic transducer, which generates longitudinal waves when excited; its working frequency is 10 kHz to 40 kHz and the output power of a single exciter shall be greater than 50 W.

6.5 Clamping device. The clamping device is the item of process equipment that fixes the exciter on the reverse side of the working face of the substrate and applies a certain clamping force to it. It shall ensure that the exciter is effectively fixed, with a defined clamping force, at the part of the additively manufactured metal component where stress is to be relieved; that, once the sound beam exciter is connected to the heat-insulating horn, it is tightly and stably coupled to the surface of the substrate with a constant coupling contact force; and that the acoustic wave can be injected effectively into the interior of the additively manufactured metal part.

6.6.1 Material. The heat-insulating horn shall be made of a material with good acoustic transmission and good thermal insulation (common materials being titanium alloy, stainless steel and the like), so as to reduce the loss of sound beam energy as far as possible while lowering the heat conducted to the exciter during the additive process, keeping the working temperature of the exciter below 80 degrees Celsius.

6.6.2 Structure. The structure of the horn shall be designed in the light of the performance of the exciter and the requirements of the stress control process so as to ensure its amplitude-transforming performance; the front end face of the horn shall be so shaped that it fits closely against the surface of the substrate or the surface of the additively manufactured part.

6.7 Couplant. The couplant shall achieve good coupling between the exciter or the horn and the reverse side of the working face of the substrate or the surface of the additively manufactured part, so that the ultrasonic energy is injected effectively into the part. The couplant shall be easy to clean off and shall not corrode or otherwise damage the surface of the substrate or of the additively manufactured part. Couplants in common use include high-temperature grease, glycerol and acoustically transparent rubber; for sound beam control of residual stress during the additive process a heat-resistant couplant shall be used.

7 Working process

7.1 Workflow. Sound beam control of residual stress generally comprises preparation before work, simulated running and commissioning of the sound beam control, residual stress control, and assessment of the effect of the residual stress control; the workflow is shown in Figure 3. Once the reasonable layout of the exciters and the control process have been decided, simulated running and commissioning of the sound beam control are first carried out according to the additive process path, and the sound beam control process is then implemented according to the workflow below.

7.2.1 Design requirements. The design shall meet the following requirements: a) the distribution of residual stress in the additively manufactured component shall be studied on the basis of the material, the structure and the additive process, and the scheme for sound beam control of residual stress shall be determined from that distribution and from the control indices; b) for a metal part made by an additive manufacturing process, the technical requirements for the residual stress of the part and its distribution shall be marked using the symbols specified in GB/T 40121.

7.2.2 Arrangement of the exciters. The regions of stress concentration arising in production shall be determined from the structure of the additively manufactured metal part and the material used, and the positions of the exciters and the direction of the sound beam determined accordingly. The arrangement of exciters for sound beam control of residual stress in metal parts of typical structure is given in Annex A.

7.2.3 Connection of the residual stress sound beam control system. The connection comprises the following steps: a) confirm that the connecting cable between the ultrasonic exciter and the excitation power supply is properly connected, and switch on to confirm that the exciter and the excitation power supply are working properly; b) apply the couplant evenly to the front end face of the heat-insulating horn and fix the exciter and horn with the exciter clamping fixture, so that the end face of the horn fits well against the reverse side of the working face of the substrate or against the surface of the additively manufactured part, with a reasonable coupling clamping force.