

Equiaxed vs. DS vs. SX Superalloy Casting Structures

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1. Executive summary

Equiaxed, directionally solidified (DS) and single crystal (SX) castings describe different grain structures, not three interchangeable names for vacuum casting. A conventional equiaxed casting contains grains in many orientations. A DS route controls heat flow to grow several columnar grains primarily along a selected direction. An SX route additionally selects or seeds one crystal through the required region. The appropriate route is established by the alloy and component specification, service conditions, geometry and acceptance plan. [1-5]

This paper explains the process distinctions, qualitative engineering considerations and information needed for a drawing-based manufacturing discussion. It does not set allowable temperatures, component life or production acceptance criteria.

2. Introduction to superalloy solidification

Nickel-based superalloys can be cast into complex hot-section geometry. During solidification, grains form and grow; their arrangement influences boundary orientation and direction-dependent response. Melting practice, mold design, thermal gradient, solidification front, heat treatment and inspection control different parts of the final material condition. A structure label alone cannot establish alloy suitability or component life. [1, 2]

3. Equiaxed casting

In a conventional equiaxed casting, grains nucleate and grow in multiple directions, producing boundaries with varied orientations. This can be appropriate when the approved design specifies that structure. Chemistry, heat treatment, soundness, dimensions and any grain-condition limits still require verification. Conventional does not mean inspection-free.

4. Directionally solidified casting

A DS route creates a controlled thermal gradient and advancing solidification front. Favorably oriented grains extend as columns along the growth direction; boundaries remain between columns but fewer are transverse to that direction than in a typical equiaxed structure. Bridgman-type processing is one way to control the front through a heated and cooled zone. Growth direction, grain defects and section transitions require specified controls. [1-3]

Longitudinal boundaries still matter. A NASA study of a DS nickel-base alloy identified boundary misorientation as one influence on deformation; specimen results do not establish universal blade allowables. [2]

5. Single crystal casting

An SX route uses directional growth plus a selector that lets one grain continue, or a specified seed that establishes the intended crystal. A successful single crystal lacks conventional high-angle boundaries through the required region. Orientation, stray grains, low-angle boundaries and recrystallized areas can remain acceptance concerns. [1, 4, 5]

Crystal orientation relative to blade geometry is an engineering input in NASA blade analysis; an alloy name alone cannot define that relationship. [4]

6. Equiaxed vs. DS vs. SX: technical comparison

Criterion	Equiaxed	DS	SX
Grain structure	Multiple grains in varied orientations	Multiple aligned columnar grains	One selected crystal in the specified region
Grain boundaries	Many boundaries in varied directions	Longitudinal boundaries remain; transverse boundaries reduced	No conventional high-angle boundaries in a sound crystal; defects still matter
Solidification	Conventional mold freezing to specified condition	Controlled heat extraction and directional growth	Directional growth plus grain selection or seeding
Creep and cycling	Depends on alloy, boundaries and load direction	Direction-dependent response needs alignment control	Orientation-dependent response and defect control
Complexity	Specified casting and thermal controls	Additional gradient, growth and grain-direction controls	Additional selector/seed, orientation and stray-grain controls
Material examples	Specified conventional cast grade	Specified DS variant; published Mar-M 247 blade examples	Specified SX grade such as CMSX-4
Turbine application	Designed for equiaxed structure	Selected airfoils requiring columnar growth	Selected airfoils requiring one oriented crystal
Inspection focus	Grain condition, soundness, dimensions	Growth direction, grain defects, soundness, dimensions	Orientation, unwanted grains, soundness, dimensions

This qualitative table does not provide an allowable temperature, life, interchangeable alloy grade or approved manufacturing route. The governing specification controls the actual part.

Why the table is not a material ranking

Boundary geometry, crystal direction, chemistry, heat treatment, cooling design and service cycle interact. A structure can address one failure mechanism while leaving others unchanged. The SX column does not automatically override DS or equiaxed for every design.

7. Melting versus solidification: VIM, DS and SX

Vacuum induction melting (VIM) controls the melt environment when required for the alloy and casting route. DS and SX describe how the melt solidifies and what grain structure is produced. Vacuum melting does not automatically produce columnar grains or one crystal; the specified structure does not replace melt chemistry and cleanliness controls. These requirements belong separately in the process plan.

8. Turbine application and process selection

Begin with component location, service temperature and stress cycle, cooling design, coating and the design-approved material definition. Compare the required grain structure with mold geometry, thermal processing and inspection. A turbine blade enquiry adds airfoil walls, passages, platform, root and tip interfaces. Do not select DS or SX solely from a higher-temperature label. [2-5]

Questions before comparing manufacturing routes

- Which drawing revision, duty cycle and design-approved material definition govern the part?
- What grain structure and growth or crystal orientation are required relative to part datums?
- Do section changes, cooling passages, core location or coating alter the process or inspection scope?
- Are quotes for castings, heat-treated parts or finished and released components with equivalent records?

9. Inspection and specification considerations

Specify the exact alloy and variant; required equiaxed, DS or SX structure; any growth or crystal-orientation limits; heat treatment; permitted repair; casting soundness; dimensional and passage checks; coating condition; NDT methods; and release records. Methods and limits must be traceable to approved design and purchase documents. Casting-only and finished-part supply have different responsibility boundaries.

Keep acceptance questions separate

Structure examination establishes grain condition; orientation measurements relate growth or lattice direction to part geometry; soundness methods address discontinuities; metrology and passage checks address geometry. One accepted result cannot close the others. SX structure can require examination before and after thermal processing. [5]

10. Conclusions

Equiaxed, DS and SX structures address different design and production requirements. VIM is a melting control, while directional growth and grain selection establish DS and SX structures. The specification, not a generic chart, determines the route for a particular component. For a manufacturing discussion, send the drawing and approved material, structure, inspection and delivery requirements.

11. References

- [1] NASA, Solidification process control for advanced superalloys.
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