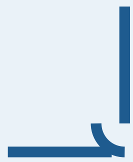
KINGSFORM METALWORKS

ENGINEERING TOOLKIT

BEND RADIUS REFERENCE

Sheet-metal and tube radius selection, bend severity, tooling, springback and inspection

SHEET METAL

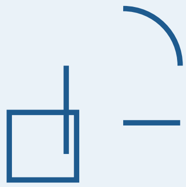


Inside radius, K-factor, bend allowance and grain direction.

ROUND TUBE

Centerline radius, wall factor, ovality and thinning.

SHS / RHS



Section orientation, corner distortion and twist control.

DOCUMENT	VERSION	RELEASE DATE	LANGUAGE
KFR-015	1.0	2026-07-17	English
FORMAT	OWNER	CONTACT	WEBSITE
A4 PDF	KingsForm Engineering	info@kingsformmetalworks.com	www.kingsformmetalworks.com

Engineering reference only. Final bend radius, tooling, tolerances and acceptance limits require supplier confirmation and project-specific validation.

01 USE AND DECISION HIERARCHY

Treat bend radius as a process decision - not a drawing decoration

Radius selection links material condition, section geometry, tooling, appearance, tolerance and production volume.

Decision layer	Question to answer	Controlling information	Release output
Function	What envelope, flow path, stiffness or clearance is required?	Installed interfaces, loads, mating parts, service access	Target geometry and critical dimensions
Material	Can the selected grade and temper tolerate the strain?	Product form, thickness/wall, temper, grain, weld seam	Candidate minimum radius range
Process	Which machine and tooling can form the part repeatedly?	Press brake, rotary draw, roll bend, stretch bend, tooling stack	Approved production radius and straight lengths
Quality	How will the result be verified?	Angle, profile, ovality, thinning, cracks, twist, cosmetics	Inspection method and acceptance limits

Three rules that prevent expensive rework

- **Specify the radius type.** Sheet-metal drawings normally control inside radius; tube drawings normally control centerline radius (CLR).
- **Separate design intent from supplier capability.** A 1D tube bend or a zero-inside-radius sheet bend may be geometrically possible yet unsuitable for the selected grade, wall, tooling or appearance requirement.
- **Validate the production route.** Prototype the combination of material lot, bend direction, tooling, lubricant, speed and inspection method that will control the released part.

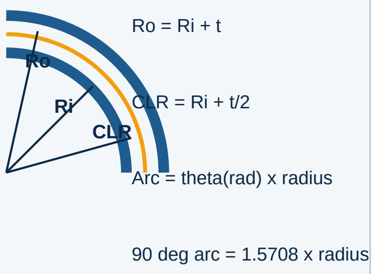
Screening values in this guide are starting points. They are not universal minimums and do not override material standards, OEM tooling limits, purchased specifications or qualified process data.

02 GEOMETRY AND EQUATIONS

Name the radius correctly before calculating length or strain

Inside radius, centerline radius and outside radius are related, but they are not interchangeable on drawings.

RADIUS DEFINITIONS



Sheet: Ri = inside radius; tube: CLR = centerline radius

CORE EQUATIONS

Tube arc length along CLR
Larc = theta(rad) x CLR

Sheet bend allowance
BA = theta(rad) x (Ri + K x t)

Outside setback for 90 deg
OSSB = (Ri + t) x tan(theta/2)

Tube radius ratio
R/D = CLR / outside diameter

Wall factor
WF = outside diameter / wall thickness

Approx. outer-fibre strain
epsilon ≈ t / (2Ri + t) for sheet; use only as a trend indicator

Worked examples

Case	Inputs	Calculation	Result
90 deg tube bend	CLR 50 mm	1.5708 x 50	78.54 mm arc length
90 deg sheet bend	Ri 2 mm; t 1.5 mm; K 0.38	1.5708 x (2 + 0.38 x 1.5)	4.04 mm bend allowance
Tube severity	OD 25 mm; wall 1.5 mm; CLR 37.5 mm	R/D = 1.50; WF = 16.7	Moderate screening case; confirm tooling and cosmetic limits

Do not back-calculate a guaranteed flat length from a generic K-factor or a nominal CLR. Production data should be established with the actual tool radius, material condition, thickness/wall tolerance and springback compensation.

03 SHEET-METAL RADIUS

Use material condition and bend direction to select the starting radius

The same alloy designation can bend very differently after changes in temper, thickness, grain direction or surface condition.

Material / condition	Preliminary inside-radius screen	Risk modifiers	Release action
Low-carbon steel, annealed / commercial quality	~0.8t to 1.5t	Thicker plate, high-strength grade, edge quality, coating	Confirm actual grade and press-brake tooling
304 / 316 austenitic stainless, annealed	~1t to 2t	Work hardening, polished face, bend across/with grain	Increase radius for cosmetic or crack-sensitive surfaces
5052-H32 aluminum sheet	~1t to 1.5t	Grain direction, thickness, tight hems	Prefer bend axis across rolling direction
6061-T6 aluminum sheet	~2t to 4t or more	Low ductility in T6, sharp laser edges, with-grain bend	Consider larger radius, alternate temper, or form then heat treat
High-strength / spring steel	~2t to 5t+	Yield strength, hardness, edge condition, large springback	Require material-specific bend data and trials

Radius alone does not control bendability

- **Grain direction:** bending with the bend axis parallel to rolling direction typically raises cracking risk in less-ductile sheet.
- **Edge condition:** burrs, heat-affected cut edges and sheared fracture zones can initiate cracks.
- **Tooling:** air bending produces a radius related to die opening and material response; bottoming/coining behave differently.

Surface: brushed, polished or coated faces may need larger radii, protective film and dedicated tooling.

Thickness tolerance: affects final angle, radius and flat length even when nominal material is unchanged.

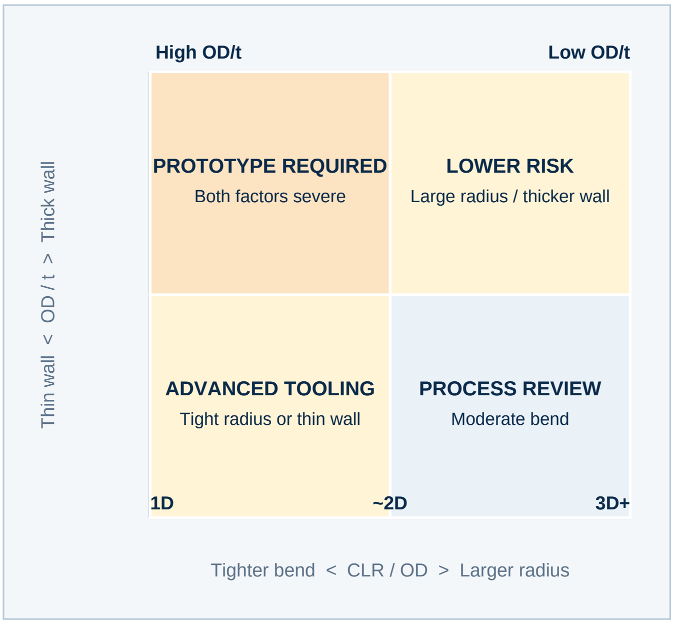
Bend sequence: a feasible single bend may become impossible after adjacent flanges block the tool.

Drawing note: identify the required inside radius only where it is functionally important. Otherwise control the material, process, bend angle and envelope, and allow the qualified fabricator to use its proven tooling radius.

04 TUBE BEND SEVERITY

Screen tube bends with radius ratio and wall factor - then review the actual process

R/D and OD/t help identify risk, but seam position, material temper, bend angle, tooling and acceptance criteria decide feasibility.



Screening band	Typical interpretation	Tooling / proce
CLR/OD >= 3	Large-radius bend; lower section distortion risk	Compression, ro push or roll benc viable
CLR/OD ~1.5 to 3	Common controlled bend range	Rotary draw tool may be needed rises
CLR/OD ~1.0 to 1.5	Tight bend	Advanced mand control and proto validation
CLR/OD < 1	Exceptional geometry	Specialized proc and acceptance

Risk factors that can move a bend into a harder category

- **High wall factor (OD/t):** thin walls are more prone to wrinkle, collapse and ovality.
- **Large bend angle:** distortion accumulates over a longer arc.
- **Weld seam:** ERW seam position and local properties can affect appearance and repeatability.
- **Square / rectangular tube:** inside-wall buckling, side-wall concavity and corner movement require section-specific tooling.
- **High-strength material:** raises force and springback; low elongation raises cracking risk.
- **Cosmetic limits:** a structurally acceptable bend may still fail visible-surface criteria.

Commercial mandrel-bending equipment commonly targets radii near 1.5D to 2D for suitable tubes, but this is machine- and application-dependent. Do not convert an equipment brochure capability into a blanket part approval.

05 PROCESS AND TOOLING

Match the radius to the bending method and support package

The same nominal CLR can produce different ovality, thinning, wrinkle and surface marks depending on the forming route.

Method	Best use	Radius behavior	Key limitations
Rotary draw bending	Repeatable tight and multi-plane tube bends	Fixed bend-die CLR	Needs clamp length; mandrel/wiper/boost may be required
Compression bending	Simple single-plane bends	Tool-defined; usually less control than rotary draw	Higher flattening risk on tighter or thinner sections
Roll bending	Large-radius arcs and rings	Radius built gradually, often variable	Long tangents, end flats and springback control
Push / freeform bending	Large or changing radii, 3D paths	Programmable variable radius	Machine-specific calibration and profile verification
Press-brake air bending	Sheet and plate flanges	Inside radius emerges from die opening and material	Angle/radius vary with thickness, strength and tooling
Bottoming / coining	Controlled sheet angle/radius in selected work	Closer tool imprint	Higher force; surface and tooling constraints

Rotary-draw tooling functions

Tool element	Primary function	Typical symptom when setup is inadequate
Bend die	Defines CLR and supports outer arc	Wrong radius, surface pickup or profile mismatch
Clamp die	Transfers bending force without slipping	Slip marks, angle inconsistency, short-end instability
Pressure die / follower	Supports and feeds the outside wall	Excess thinning, drag marks, poor material flow
Mandrel	Supports the inside of the tube through the bend	Collapse, ovality or excessive thinning
Wiper die	Controls the compressive inside wall near tangent	Wrinkles or ripples on the inside radius
Booster / push assist	Feeds material into the bend	May reduce thinning when correctly tuned; can destabilize setup if excessive

Specify surface areas that must remain mark-free. Tight-radius tooling often requires contact pressure and lubrication; cosmetic requirements can change tool material, polishing, protection and allowable witness marks.

06 STRAIGHT LENGTHS AND CUT LENGTH

Design enough tangent for clamping, support and part extraction

A mathematically correct radius can still be unmanufacturable when the ends or adjacent bends do not leave usable tooling space.

Geometry item	Design check	Preliminary planning guidance
End straight before first bend	Can clamp and feed the part without gripping a formed end?	Reserve actual clamp length plus trim allowance; obtain machine-specific minimum
Straight between bends	Can the pressure/clamp dies clear the previous bend?	Use tooling envelope, not only tangent-to-tangent distance
Reverse bends / S-bends	Can the head rotate and the part clear the machine?	Check bend direction, plane rotation and collision simulation
Large-radius roll bends	Can the rolls grip both ends of the arc?	Expect unformed end flats unless extra stock is trimmed
End forms / nuts / flanges	Can preformed ends pass through tooling and collets?	Decide operation sequence before freezing cut length
Cut length	Are arc lengths measured on the correct line?	Use CLR for tube; neutral-axis bend allowance for sheet

Cut-length workflow for a bent tube

1. Freeze each straight dimension to the tangent or end datum.
2. Calculate each arc length: theta(rad) x CLR.
3. Add end trims, saw/laser kerf and operation allowances.
4. Apply validated elongation or compression correction from trial parts.
5. Measure the first article and update machine data - not the released geometry.

Do not put a tight dimensional tolerance on raw cut length when the customer function is controlled by end-to-end geometry after bending. Control the functional final datums and let the process absorb cut-length compensation.

07 FEATURES NEAR BEND ZONES

Keep holes, slots, welds and inserts away from unstable material flow

Features placed in or beside the bend can stretch, rotate, close, crack or become inaccessible to tools and gauges.

Feature	Main risk	Preliminary DFM screen	Preferred response
Sheet hole near bend	Elongation, teardrop shape, edge pull	Hole edge to bend line >= Ri + 2t as a starting point	Move feature, increase relief, or make after bending
Sheet slot parallel to bend	Slot wall distortion and crack initiation	Use more spacing than a round hole; review slot-end radius	Add formed relief or secondary operation
Tube hole in bend arc	Oval hole, location shift, wall tear	Avoid on tight/high-WF bends unless trial data exists	Laser/drill after bend or fixture-gauge final feature
Weld seam in tube bend	Local stiffness / appearance variation	Define or control seam orientation where functionally important	Supplier to prove seam position and process window
Weld nut / boss near bend	Tool collision and local restraint	Check full tool stack and heat sequence	Bend first, weld later unless qualified otherwise
Coating / plating	Cracking, galling, thickness loss	Review bend before/after finish route	Mask, protect or finish after forming

Datum and inspection implications

- **Dimension from stable final datums.** A hole located from a raw tube end may drift after trim and bend compensation; a final fixture datum can be more repeatable.
- **Separate form from position.** Control the bend profile or envelope independently from the location of a functional hole pattern.
- **Define inspection state.** State whether the part is free-state, restrained in a checking fixture, or assembled when dimensions are verified.
- **Plan access.** A feature may be manufacturable but impossible to gauge after an adjacent flange or bend closes the access path.

For sheet metal, Ri + 2t is only a practical starting screen for a round hole. Material, hole size, bend angle and tooling can require more distance. Tube features inside a bend should always be reviewed with the actual bend process.

08 SPRINGBACK AND MULTI-PLANE BENDS

Compensate the process - preserve the nominal drawing geometry

Springback is elastic recovery after unloading. It changes angle, radius and sometimes plane rotation; compensation belongs in qualified machine data.

Springback tends to increase with	Springback tends to decrease with	Control method
Higher yield strength / lower elastic modulus ratio	More plastic strain and tighter forming	Trial bends, material-lot control, overbend calibration
Larger radius-to-thickness ratio in sheet	Bottoming/coining or stretch effects where appropriate	Angle measurement under consistent fixture state
Higher-strength tube or larger CLR/OD	Mandrel/boost/tooling that stabilizes material flow	Machine compensation tables and first-article correction
Material variation, thickness variation and anisotropy	Stable incoming material and tool condition	Record grade, temper, lot, wall/thickness and tool ID

Multi-plane bend definition

Coordinate method	What it defines	Risk if incomplete
LRA - length, rotation, angle	Feed to next bend, rotation around tube axis, bend angle	Ambiguous tangent basis or sign convention
YBC - XYZ intersection or endpoint data	Machine-generated coordinates of bend geometry	Wrong datum or centerline interpretation
3D CAD centerline + end orientation	Nominal path and clocking of end features	No tolerance, no bend sequence, no seam control
Drawing with basic dimensions + profile/position	Functional geometry and inspection relationship	Overconstraint if every local length and angle is also tightly toleranced

Do not revise the released bend angle simply to match an overbend machine setting. The drawing should state the required finished geometry; the routing or CNC program carries the compensation.

09 QUALITY AND INSPECTION

Define what “good bend” means before the first article

Angle alone is not enough. A bend may meet angle while failing profile, ovality, wall thickness, twist, crack or cosmetic requirements.

Characteristic	Calculation / method	Engineering note
Ovality	(Dmax - Dmin) / Dnom x 100%	Measure at the defined section and orientation; acceptance is project-specific
Wall thinning	(t0 - tmin) / t0 x 100%	Use suitable ultrasonic or sectioned measurement; know original wall tolerance
Wrinkle / ripple	Visual comparator, depth or profile scan	Define whether cosmetic, flow or fatigue performance controls
Bend angle	Fixture, digital inclinometer or CMM	State datum setup and free/restrained condition
Bend radius / profile	Template, contour gauge, scan or CMM profile	A nominal tool radius does not guarantee finished CLR
Twist / plane rotation	Fixture targets, CMM, laser tracker	Critical on multi-plane parts and rectangular sections
Cracks / surface damage	Visual, PT or project-required NDT	Inspection method must match material, finish and consequence

Acceptance plan by project phase

Phase	Recommended evidence
Prototype	Material certificate; tool identification; bend settings; section/profile measurements; photographs; destructive section if risk warrants
First article	Ballooned drawing; final-datum inspection; ovality/thinning results where specified; fit check; approved cosmetic sample
Production	Defined sampling; go/no-go fixture or CMM routine; process parameter control; nonconformance and rework traceability
Change control	Revalidate when material source/temper, wall/thickness, tool radius, lubricant, machine, heat treatment or finish route changes

Avoid generic statements such as “no deformation.” Replace them with measurable limits tied to a location, inspection state, method and sampling plan.

10 QUICK LOOKUP AND RELEASE CHECK

Use lookup values to start the conversation - not to bypass DFM

The tables below convert common radius ratios. The checklist confirms that the drawing and RFQ contain the information needed for supplier review.

OD mm	1D CLR	1.5D CLR	2D CLR	3D CLR
12	12.0	18.0	24.0	36.0
16	16.0	24.0	32.0	48.0
20	20.0	30.0	40.0	60.0
25	25.0	37.5	50.0	75.0
32	32.0	48.0	64.0	96.0
38	38.0	57.0	76.0	114.0
50	50.0	75.0	100.0	150.0
60	60.0	90.0	120.0	180.0
76	76.0	114.0	152.0	228.0

24-point bend-radius release checklist

1 Product form and governing material standard stated
2 Grade, temper / condition and thickness or wall stated
3 Radius type identified: Ri, CLR or Ro
4 Nominal bend angle and direction defined
5 Grain direction or tube seam requirement reviewed
6 Bend method and tooling route confirmed
7 R/D and OD/t severity screened for tube
8 Sheet radius range validated for material condition
9 End straight / clamp length confirmed
10 Straight between bends checked against tooling
11 Bend sequence and machine collision reviewed
12 Arc and cut-length basis defined

13 Holes / slots clear of unstable bend zone
14 Inserts, nuts and welds sequenced correctly
15 Coating or cosmetic surfaces protected
16 Springback compensation plan established
17 Final datums and inspection state defined
18 Angle, profile and rotation tolerances rationalized
19 Ovality / thinning limits specified where needed
20 Crack, wrinkle and witness-mark criteria defined
21 Prototype / first-article validation planned
22 Production sampling and gauge method defined
23 Material / machine / tooling changes controlled
24 Supplier DFM approval recorded before release

A completed checklist is not a substitute for a supplier capability statement. Tight radii, thin walls, high-strength materials, critical cosmetics and multi-plane geometry should be released only after documented DFM review.

11 STANDARDS AND SOURCE LINKS

Verify the governing edition before contract release

These official publisher pages are starting points. Purchase and apply the controlled standard when it governs testing, tolerancing or acceptance.

Reference	Application	Official source
ISO 7438:2020	Bend testing of metallic material test pieces; excludes full-section tubes and welded joints	https://www.iso.org/standard/72187.html
ISO 8491:1998	Bend test for metallic tube in full section; confirmed current in 2020	https://www.iso.org/standard/30444.html
ISO 8492:2013	Flattening test for circular metallic tubes	https://www.iso.org/standard/63853.html
ASTM E290-22	Bend testing of material for ductility	https://store.astm.org/e0290-22.html
ISO 1101:2017	Geometrical tolerancing symbols and interpretation	https://www.iso.org/standard/66777.html
ISO 5459:2024	Datums and datum systems in technical product documentation	https://www.iso.org/standard/87855.html
ASME Y14.5-2018 (R2024)	Dimensioning and tolerancing / GD&T;	https://www.asme.org/codes-standards/find-codes-standards/y14-5-dimensioning-tolerancing
Unison - rotary draw bending	OEM explanation of rotary-draw tooling and wiper-die function	https://www.unisonltd.com/knowledge/principles-of-rotary-draw-bending/
transfluid - mandrel bending	OEM machine/tooling reference; 1.5D and 2D examples are capability-specific	https://www.transfluid.net/solutions/t-work-mobile-and-compact-tube-processing-machines/compact-tube-bending-machines-mandrel-bending-machines

Copyright note: This guide provides original calculations, screening ranges and engineering interpretation. It does not reproduce proprietary standard tables or certify a bend process. Obtain the controlled standard and supplier process approval when they govern the order.

PROJECT HANDOFF

Send the drawing, 3D model, material condition, finish, quantity, inspection limits and sample expectations for manufacturability review.

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Disclaimer

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