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Strategic Radii in Structural Part Design

A Performance-Driven Approach Balancing Mechanics and Aesthetics

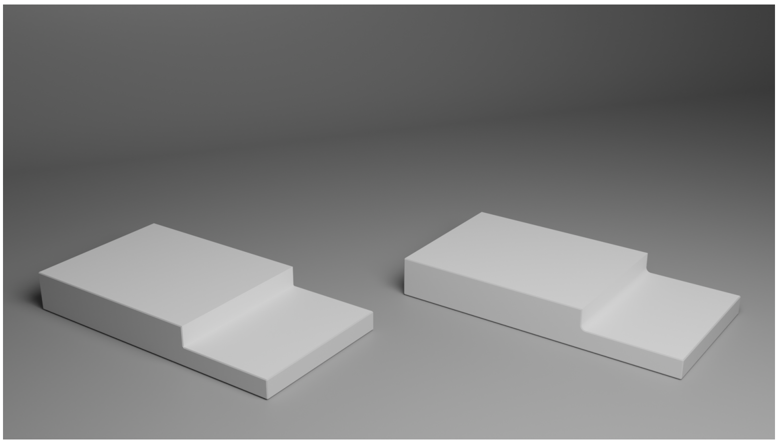

Figure 1: Sharp edges create stress peaks - radii distribute them

Abstract

Radii at feature transitions are fundamental to achieving robust plastic components with superior surface quality. These transition elements present a critical design challenge: they must be large enough to effectively manage stress concentrations while remaining small enough to avoid optical defects such as sink marks.

Optimal radii sizing of 25-40% of the local wall thickness provides the best balance between mechanical performance and aesthetic quality. This range effectively distributes stress concentrations that develop under loading while preventing material accumulation that causes sink marks on visible surfaces. Undersized radii create stress peaks and unfavorable stress states that can initiate cracking, while oversized radii lead to molding defects.

At feature intersections and complex geometries, more generous radii are recommended to accommodate the multi-directional stress states that develop in these areas. For example, when designing ribs, the arrangement should follow anticipated force flows with adequate spacing (minimum 2.5x wall thickness) between parallel features, where radii at the rib base provide the critical stress transition.

For mechanically demanding applications, radii should maintain a minimum absolute dimension of 0.5mm for structural integrity and manufacturing requirements, ensuring adequate stress distribution even in thin-walled sections while facilitating proper mold filling.

Things to consider

- Avoid sharp edges that create stress concentrations and mechanical weak points
- Prevent excessive radii that cause material accumulation and sink marks
- Use larger radii at rib intersections to distribute stress more evenly
- Ensure radii are large enough to facilitate proper mold filling and uniform cooling rates during injection molding

Introduction

In structural plastic component design, the transition between features represents one of the most critical yet often overlooked design decisions. Sharp edges and abrupt geometry changes create stress concentrations that might compromise mechanical performance, while oversized radii can lead to aesthetic defects that render components unsuitable for visible applications.

Traditional approaches treat radii as manufacturing requirements rather than strategic design tools. However, properly engineered radii enable designers to guide stress flows while maintaining surface quality — particularly critical with high-performance materials like Makrolon® polycarbonate, where effective stress management is essential to realize the material's superior mechanical properties.

Part Design for Tough Applications

Although an amorphous thermoplastic material, unreinforced Makrolon® polycarbonates are very tough engineering materials that can absorb high amounts of impact energy through plastic deformation. As an example, Table 1 shows Izod notched impact strength of selected grades, demonstrating that energy absorption of even notched specimens is still very high and exhibits ductile behavior.

Makrolon® Grade	23 °C (kJ/m²)
2807	70
6487	70
FR6020	62
FR6040	65

Test conditions: ISO 21305/based on ISO 180/A, 3mm thickness

Table 1: Izod Notched Impact Strength for Selected Makrolon® Grades

But the physics behind the necessity for radii is still straightforward. Sharp edges and abrupt geometry changes create stress concentrations with high stress triaxialities that can exceed the material's local strength, leading to crack initiation and premature failure. Although Makrolon® is generally very tough, this ductile-to-brittle transition is common for polycarbonates under high stress concentrations. Therefore, part design must help avoid such critical geometries and allow suitable stress flow.

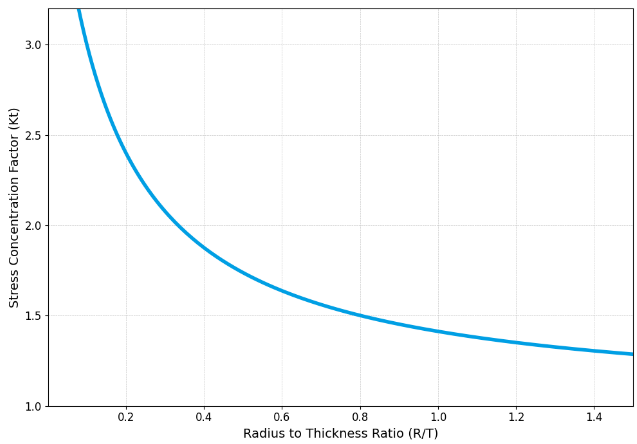

Figure 2: Stress concentration factors as a function of radius and wall thickness

As shown in Figure 2, the relationship between radius size and stress concentration factor demonstrates this critical design relationship. Conversely, oversized radii create areas of material accumulation during injection molding, resulting in differential cooling rates that manifest as visible sink marks on component surfaces.

At feature intersections and complex geometries such as rib intersections, corner transitions, and screw bosses, the stress state becomes multi-dimensional, requiring generous radii where standard sizing rules must be adapted. For rib design, the arrangement should follow anticipated force flows with adequate spacing between parallel features. Minimum spacing of 2.5× wall thickness between parallel ribs prevents stress interaction while allowing proper material flow during molding. Radii at rib bases provide the critical stress transition from the thin rib section to the thicker base wall, requiring careful attention to both mechanical and molding considerations.

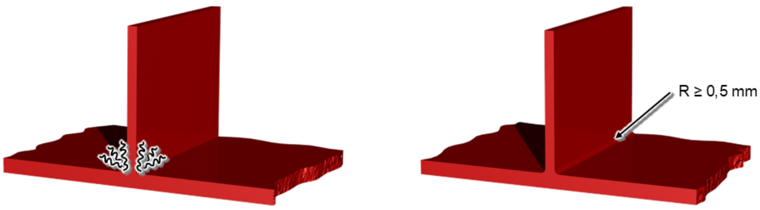

Figure 3: Always assure minimal radii in highly stressed areas

Extensive analysis and field experience have established that radii sized at **25-40%** of the local wall thickness provide the optimal balance between mechanical performance and aesthetic quality. This range effectively distributes stress concentrations while preventing the material accumulation that causes molding defects. This percentage-based approach ensures proportional scaling across different wall thicknesses, maintaining consistent stress distribution characteristics regardless of component size.

In mechanically demanding applications, radii should maintain a minimum absolute dimension of **0.5mm** regardless of calculated percentages. This ensures adequate stress distribution in thin-walled sections and facilitates proper mold filling during manufacturing (Figure 3).

FEA Validation in Part Design

Modern finite element analysis tools enable designers to validate radii effectiveness before committing to tooling. Stress analysis should focus on peak stress magnitudes and stress gradients, ensuring that radii successfully transform sharp stress peaks into manageable stress distributions. In addition, evaluation of stress triaxiality helps identify critical areas where material failure modes may transition from ductile to brittle behavior. The goal is not to eliminate stress entirely, but to create stress states that remain within the material's capabilities under expected loading conditions.

For effective design validation without excessive simulation effort, FEA is usually performed without explicitly modeling detailed features or small radii. Critical stress concentration areas will clearly emerge from the analysis, indicating where radii must be strategically added to manage stress flows. This approach allows designers to identify problem areas early in the design process and apply appropriate radii sizing guidelines before detailed modeling.

For complex applications and strategic projects, Covestro offers specialized simulation support, including validated material cards calibrated for different types of mechanical simulation and technical consultation services. This expertise ensures accurate material property representation in FEA models, leading to reliable design predictions and optimized material selection.

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[1] Siehe Leitfaden für den Einsatz von Covestro-Produkten in einer Medizinischen Anwendung