WARM DEEP DRAWING PROCESS OF STAINLESS STEELS

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1. Introduction

Deep drawing is a complex forming process which involves tension (cup wall), bending (punch and die corners) and compression (cup flange). Both high tensile strength and better ductility in compression are required for the deep drawing material.

Although the deep drawing process of high strength/low formability metals has an extensive industrial application area, deep drawing at room temperature has serious difficulties because of the large amount of deformations and high flow stresses of the materials. Thus drawing at elevated temperatures decreases the flow stresses, relieve residual stresses and hence increases the formability of the materials as deformations become easier.

Extra-deep drawing (EDD) steels are the most widely used steel material today for automotive applications involving simple and complex components, which require very high formability. Exterior components such as starter end covers, petrol tanks, are made up of deep drawing grade steels. The low carbon steel sheets are also used extensively in enameling applications such as baths, sink units, kitchen ware, cooker and refrigerator panels.

Because of re-crystallization, the temperature is one of the notable points during the forming process. The temperature during the warm deep-drawing should be kept below the re-crystallization temperature. The temperature affects the material behavior during the process and accuracy of finished parts. In comparison to hot forming processes, warm forming requires higher forces for deformation because of the greater material flow stress.

Warm deep-drawing for aluminum alloys has already been reported by many researchers. Warm deep-drawing experiments on various aluminum alloys (1050, 5754-O and 6016-T4) were carried between 100^{o} C and 250^{o} C using box shaped and conical rectangular dies. These studies showed that raising temperature increased formability.

In the investigation of stainless steel AISI 304, 1.0 mm thick circular specimen were warm deep drawn and the influence of temperature on the deformation behaviour of material and the drawing loads which is required to draw the component was studied. The results show that the warm working has positive effects like reduced drawing load, negligible amount of increase in thinning and thickening of a drawn component when compared to the conventional drawing and also there is no necking or cracking occurs due to the temperature influence.

2. Account of Properties of Stainless Steels

The stainless steel alloy properties related to the deep drawing process:

Malleability - Malleable, meaning that stainless steel can be deformed, bent, change its original shape to be molded into more complex and three-dimensional forms. This is relevant as the material maintains its capability of being extended without losing its natural strength.

Thermal resistant - as it can endure high temperatures without losing its inherent properties. This makes the deep drawing of stainless steel an incredibly versatile procedure, allowing creating several components for many different industrial applications.

Chemical resistant - as stainless steel seems immune to oxidation and chemicals, ensuring durability over time of the products manufactured with the deep drawing technique.

Elasticity and Strength - while being extremely responsive to deformations, stainless steel preserves its resistance to both static and dynamic strains post-deep drawing. For this reason, this metal is particularly suitable in the production of vehicles' parts and structural components that are continuously subjected to physical stresses.

3. Challenges Associated with Deep Draw Forming Stainless Steel

Because of unique properties of stainless steel, it requires special handling during the deep draw forming process. Stainless steel work hardens faster than carbon steel. Therefore, it requires nearly twice the pressure to be stretched and formed. It's important to tailor this pressure to material type to prevent breakage or galling. Chromium oxide surface film (which prevents corrosion) of stainless steels intensifies friction during deep draw forming, meaning that tooling must be coated and lubricated meticulously to minimize the cost of wear and tear. The speed of deep drawing stainless must be optimized to account for high friction, high pressure, depth of draw and other factors. Failing to calibrate speed correctly can result in breakage or wrinkles. In general, the more severe the draw, the slower it needs to be.

4. Stainless Steels

4.1 Stainless Steel - 201/201L

Stainless steel type 201 features a lower percentage of nickel than other stainless steel blends. This makes it less expensive, but also less corrosion-resistant. A higher manganese content makes stainless steel 201 stronger than other blends and allows it to retain strength and dimensional stability even in extremely cold environments. It is an excellent option for durable, inexpensive components in cold applications where exposure to corrosion is minimal.

4.2 Stainless Steel - 316/316L

Stainless steel type 316 is distinguished by its higher nickel and molybdenum content. Type 316 exhibits extreme resistance to corrosion and moisture in comparison with other stainless steel alloys but is also more expensive due to its high nickel content. It holds up particularly well to salt water and chlorides, which makes it useful for marine components, stainless steel floats, and medical devices.

4.3 Stainless Steel - 409

Stainless steel 409 is a temperature-resistant blend of stainless steel with higher iron content. This ferrite stainless steel contains 11% chromium, which provides good corrosion resistance. However, its greatest benefit lies in its ability to withstand extremely high temperatures. Although Type 409 exhibits a greater level of corrosion-resistance than coated iron alloys, it is less resistant than most other stainless steels. Light rust may eventually form with extended exposure to moisture or corrosive elements.

4.4 AM350 Stainless Steel Alloy
AM350 is a stainless steel alloy that contains nickel, chromium, and molybdenum. Unlike other stainless steel blends, AM350 can be heat treated to enhance formability or strength, depending on the needs of the application. Heat treatment processes used to enhance AM350 include annealing, hardening, sub-zero cooling, and double aging. Annealed AM350 exhibits a higher degree of formability, while maintaining good strength and corrosion resistance.

4.5 Alloy 20
Alloy 20 is a unique blend of nickel, iron, and chromium with a niobium stabilizer. The unique chemical composition of Alloy 20 makes it especially corrosion-resistant, particularly in the face of corrosive chemicals. Its ability to withstand extreme corrosion makes it ideal for a wide variety of harsh application environments, including: chemical and petrochemical processing, food, beverage, and dye production, heat exchangers, explosives, tanks and valves, synthetic rubber and plastics manufacturing, pharmaceuticals, SO_2 scrubbers and other extreme environments.

4.6 Other Common Grades of Stainless Steel used in Deep Drawing
Not all stainless steel grades are created equal for deep drawing:

- **304 -** Excellent formability and corrosion resistance.
- **316 -** Superior strength and chemical resistance.
- **301 -** High flexibility, ideal for complex shapes.
- **430 -** Good formability in ferritic stainless steel.

5. Challenges in Deep Drawing Stainless Steel
Deep drawing stainless steel comes with its own set of challenges. The explore common issues and how to address them effectively.

Wrinkling - It occurs when excess material gathers in the drawn part’s flange or wall. It’s often caused by insufficient blank holder pressure or improper lubrication. Wrinkles can compromise the part’s structural integrity and appearance.

Tearing - It happens when the material is stretched beyond its limits. It’s usually seen at the base or corners of deep-drawn parts. Excessive blank holder pressure or sharp tool edges are common culprits. Tears render parts unusable and increase scrap rates.

Earing - It is the formation of wavy edges on the top of deep-drawn cups. It’s caused by anisotropy in the stainless steel sheet. Earing leads to uneven part heights and can necessitate additional trimming operations.

6. How to Mitigate Deep Drawing Defects
Preventing defects requires a multi-faceted approach.
Start by optimizing the tool design.
Use simulation software to predict and address potential issues before production begins.
Fine-tune of process parameters. Adjust blank holder force, punch speed, and lubrication to find the sweet spot for each part.

Use draw beads or step plates to control material flow and reduce wrinkling.
For complex parts, multi-stage drawing can help distribute stress more evenly. This reduces the risk of tearing and allows for deeper draws. Anneal the material between stages if necessary to restore flexibility.

7. Stainless Steel's Impact on Tool Wear and Tear

Stainless steel is harder on tools compared to milder metals. Its high strength and work hardening properties accelerate tool wear. This leads to more frequent tool maintenance and replacement. Combat tool wear by selecting appropriate tool materials. High-speed steels or carbides offer better wear resistance. To extend tool life further, apply hard chrome plating or nitriding.

Proper lubrication is crucial. Use lubricants designed for stainless steel deep drawing. They create a barrier between the tool and the workpiece, reducing friction and wear.

When exposed to mechanical stress, transformations of austenite into martensite can occur in austenitic, stainless materials with nickel contents < 11%, which can further change the mechanical properties. Studies have shown that this martensite transformation is particularly influenced by process parameters such as temperature, stress state and forming rate. After reaching the target temperature of 80 °C for the blank holder, the drawing die and the blanks, the warm drawing tests was started.. Due to the change in viscosity, pronounced scoring developed after the first drawing process. In order to counteract this failure in the future, higher-viscosity oil should be used.

Figure 1: Different ear formation at room temperature formed from 1.4571 (L) & 1.4539 (R).

The flag saw test provided qualitative information about the remaining residual stresses. The figure 2 shows the high-alloy 1.4539 formed at room temperature on the left and at 80 °C on the right. The remaining residual stresses in both pots are almost identical.

There are 3 common problems which are fracture, wrinkling and earing of deep drawing a round cup. The techniques are heating both upper and lower dies, heating only the upper dies, and heating only the lower dies. Four different temperatures has been chosen throughout the experiment. The experimental result then will be compared with finite element analysis software. There is a positive result from steel material on heating both upper and lower dies, where the simulation result shows comparable as experimental result. Heating both upper and lower dies will be the best among 3 types of heating techniques.

Figure 2: Residual stresses in 1.4539 at 25 °C (L) and at 80 °C (R)

Figure 3 illustrates the comparison of thickness measured from cup wall to bottom centre of square mild steel cup with 45 mm blank size in warm deep drawing and deep drawing at room temperature. The graph shows that maximum thinning at the punch corner in warm deep drawing is about the same as deep drawing at room temperature. However, it can be seen that thickness is more evenly distributed in deep drawing at room temperature.

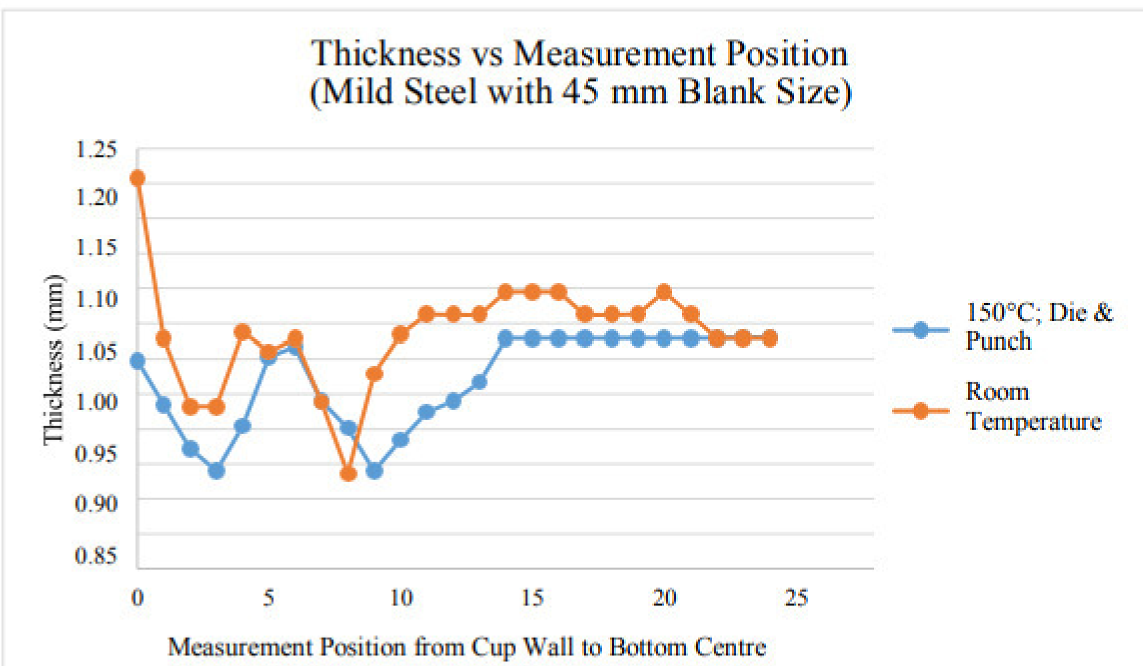

Figure 3: Thickness Distribution for deep drawn square mild steel cup with 45 mm blank size

Figure 4 illustrates the comparison of thickness measured from cup wall to bottom centre of square stainless steel with 45 mm blank size in warm deep drawing and deep drawing at room temperature. From the graph, it can be seen that maximum thinning at the punch corner is lower in warm deep drawing as compared to deep drawing at room temperature.

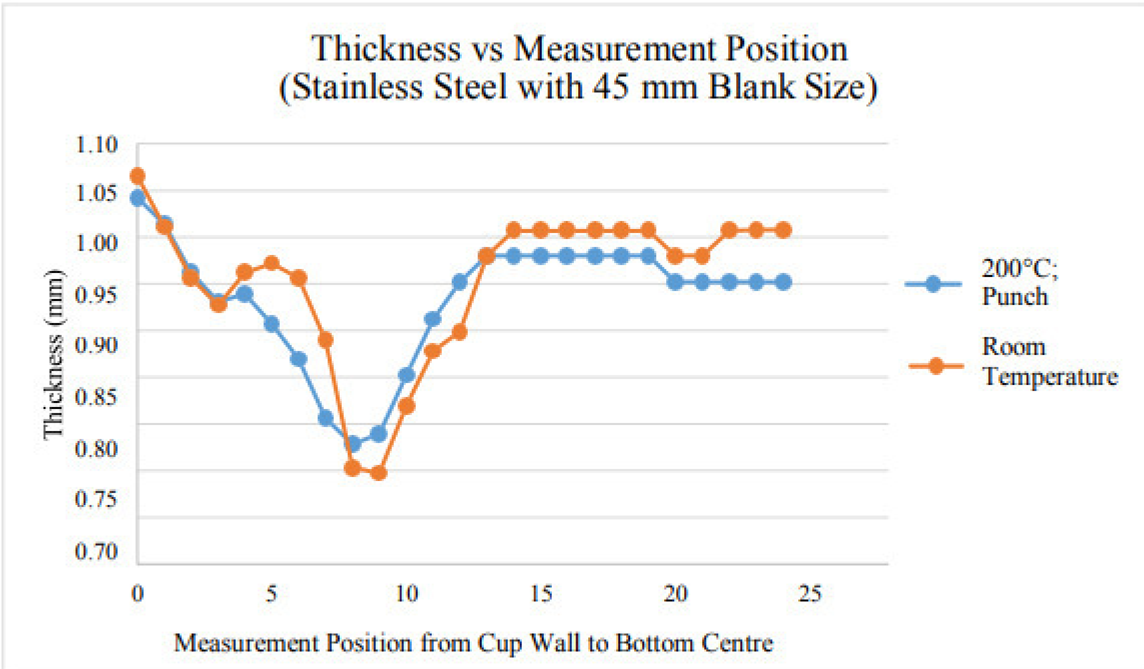

Figure 4: Thickness Distribution for deep drawn square stainless steel cup with 45 mm blank size.

6. Conclusion

For warm deep drawing of stainless steels it is required to adjust blank holder force, punch speed, and lubrication to find the sweet spot for each part. Martensite transformation is particularly influenced by process parameters such as temperature, stress state and forming rate. Heating both upper and lower dies may prevent wrinkling and earing of deep drawing a round cup.

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