Fabrication and Experimental Investigation of the Mechanical Properties of bellows for Industrial Applications

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Abstract−Bellows are fabricated using methods like hydro forming, stamping, welding, and bonding, each affecting their structural and material properties. These fabrication processes are critical in determining the performance of bellows in industrial applications. Hydro forming, for instance, uses high-pressure fluid to shape the material, providing uniform thickness and flexibility. Stamping involves pressing metal sheets into molds, while welding and bonding are used for joining parts. The present work involves fabrication of bellow through various manufacturing process and evaluating mechanical properties of bellows such as hardness, impact, compression strength of materials such as mild steel and stainless steel and it has been observed that stainless steel has superior mechanical properties when compared to mildsteel and hence stainless steel is the better choice for metal bellow manufacturing.

Keywords: Expansion bellow, Compression test on Bellow, Hydro forming, Hardness, Impact resistance, Compression strength

1. INTRODUCTION

Bellows are critical components used in various industries, including aerospace, automotive, chemical processing, and pressure systems, where they accommodate dynamic loads, absorb movement, and maintain seals during thermal expansion and contraction. They help mitigate mechanical strain, absorb vibrations, and ensure system integrity.

Despite their widespread use, the mechanical behaviour of bellows is not fully understood, especially under varying operating conditions. Factors like material selection, fatigue resistance, deformation, and the influence of bellow geometry (e.g., pleat depth and wall thickness) remain complex and inadequately explored. This research aims to optimize bellow design by improving performance across diverse industrial environments, addressing these challenges for better efficiency, durability, and reliability in critical systems.

2. LITERATURE SURVEY

In this section we have discussed some of the works of researchers in recent times in the present area, Fabrication and investigation of Mechanical properties of bellows using experimental methods approaches.

Smith et al [1] studied the fabrication of metallic bellows, focusing on hydro forming as the primary method of production. The authors found that hydro forming allowed forthe production of bellows with better uniformity and smoother fold geometry compared to traditional methods like stamping. The study emphasized the benefits of high-pressure fluid forming, as it reduced the risk of material defects and increased the fatigue life of the bellows. This method was particularly advantages for bellows used in high-pressure applications, as it resulted in bellows with a more consistent thickness and better pressure tolerance. Hydro forming was compared to conventional stamping techniques, which, while cost-effective, resulted in higher variability in material thickness and geometry, which could negatively affect the bellows' performance under stress. Smith et al. concluded that hydro forming is ideal for applications that demand high reliability and durability, as it improves the bellow’s ability to withstand cyclic loading and pressure fluctuations.

Lee and Park [2], the fabrication of stainless-steel bellows was explored, focusing on the impact of stamping on geometry and mechanical properties. The study examined how die design, stamping pressure, and material thickness affect the final shape and strength of the bellows. Variations in die geometry and stamping pressure significantly influenced the fold structure, impacting flexibility and fatigue resistance. Higher stamping pressure improved strength but reduced flexibility, while lower pressure resulted in more flexibility but lower burst resistance. The research highlighted the need to optimize the stamping process for specific applications, as the mechanical properties are closely tied to fold geometry during fabrication.

Zhao et al[3]The fabrication of elastomeric bellows was investigated, focusing on the molding process and its impact on final properties. The study highlighted how variations in curing time and temperature influenced the performance of the bellows. Different elastomer compounds were examined for their effects on tensile strength, elongation, and fatigue resistance. Longer curing times and higher temperatures improved tensile properties, while shorter curing times weakened the material. Zhao et al. emphasized the need for careful control of the molding process to achieve optimal performance. They also discussed the trade-offs between flexibility and pressure resistance, stressing the importance of balancing material selection and curing parameters for specific applications.

Wang et al[4]The influence of cooling rates on the fabrication of bellows made from high-performance alloys was studied, focusing on how cooling rate variations affected microstructure and mechanical properties. Slower cooling rates resulted in improved material strength and reduced thermal cracking. Electron microscopy analysis revealed that slower cooling allowed for more uniform grain structures, enhancing the bellows' mechanical performance. Wang et al. emphasized that controlling the cooling rate during fabrication could significantly improve the performance and longevity of bellows, particularly in high-temperature applications.

Roberts and Clark [5] investigated the impact of die design in the stamping process for metallic bellows was explored; focusing on how die geometry affects fold depth and uniformity. The study found that optimizing die design improves strength and flexibility by minimizing material deformation and ensuring consistent fold geometry. It was revealed that die design influences stress distribution, affecting fatigue resistance and pressure tolerance. Roberts and Clark recommended using computer-aided design (CAD) and simulation tools to optimize die geometries. This approach could enhance mechanical properties and ensure greater consistency across batches, improving the overall precision of the stamping process.

3. FABRICATION OF METAL BELLOW

3.1 Coil

A wound coil in the context of bellows fabrication is a coil spring (typically a metallic coil) wound into a spiral or helical shape, which is then integrated into the design of the bellow.

Coil

This coil helps control the flexibility and movement of the bellow, enabling it to withstand compressive forces, internal pressure, and dynamic motion without losing its functional integrity. In some cases, the wound coil may be used to provide pre-tensioning or to create a resistance to deformation.

3.2 Shearing

In the context of bellow fabrication, shearing refers to a cutting process where a material (often metal) is subjected to a shearing force, typically to trim or shape it, to meet specific design requirements. Shearing in bellow fabrication is commonly used to cutor trim the edges of the bellow material before it is formed into its final shape.

Shearing machine

Shearing is the process of applying a shear force to cut or separate a material, such as metal or other sheet materials, into precise shapes or sizes. In bellow fabrication, this process is often used to cut the initial sheet of material into the appropriate dimensions Before the bellows are formed, or assembled.

3.3 Rolling

In bellow fabrication, rolling is the process where a metal sheet or strip is passed through rollers to form it into a cylindrical or conical shape, a crucial step in creating the body of a bellow. This process ensures that the material is uniformly shaped and ready for further processing, such as pleating or welding. Rolling helps provide the necessary flexibility and strength for the bellow to perform under mechanical stress or pressure.

Rolling Machine

Rolling is a metalworking process used to shape a sheet or strip of material by passing it through rollers that apply pressure to bend, curve, or form the material into a specific shape, such as a tube or cylinder. This process is commonly used in bellow fabrication to create the initial tubular or cylindrical structure before the bellow is further formed, pleated, or joined.

3.4 Longitudinal seam welding

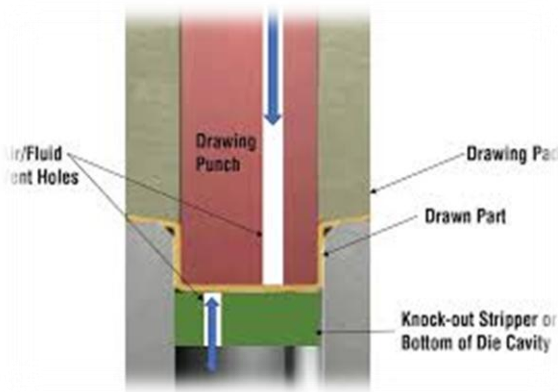
In the context of bellow fabrication, longitudinal seam welding refers to the process of welding two edges of a sheet or strip of material together along its length (longitudinal direction) to form a continuous seam. This is typically done to create the cylindrical or tubular shape of the bellow, where the edges of the rolled metal or material are joined to complete the structure before it undergoes further shaping or processing.

Longitudinal seam weldingmachine

Longitudinal seam welding is a welding process used to join the longitudinal edges of a metal sheet or strip by applying heat and pressure along the length of the material. This welding process forms a continuous, strong seam that runs parallel to the length of the bellow's cylindrical or conical shape.

3.5 Vent hole

In the context of bellow fabrication, vent holes refer to small openings or perforations that are deliberately created in the bellow's structure to allow the escape or release of air, gas, or pressure. These holes are typically located in specific areas of the bellow to ensure that it functions properly in systems where pressure changes, vacuum conditions, or air circulation need to be managed. Vent holesare small openings or perforations strategically placed in the bellow's surface to allow the controlled release of air, gases, or other substances. They are used to maintain pressure balance, prevent vacuum formation, or ensure ventilationwithin the bellow.



Vent holes machine

Vent holesare small openings or perforations strategically placed in the bellow's surface to allow the controlled release of air, gases, or other substances. They are used to maintain pressure balance, prevent vacuum formation, or ensure ventilationwithin the bellow.

3.6Hydro bellow forming

Hydro bellow formingis a specialized manufacturing process used in bellow fabrication that utilizes hydraulicpressure to form or shape a bellow. This technique is commonly used to create metal bellows by applying high-pressure fluid to a metal tube or sheet to form the desired shape, typically a cylindrical or pleated structure.

Hydro bellow forming machine

Hydro bellow forming is a process where high-pressurehydraulic fluid is applied to a tube or metal sheet inside a mold to form it into the desired bellow shape. The fluid pressure causes the material to expand and take on the form of the mold, creating the pleats or accordion-like structure typical of a bellow.

3.7 Inner Sleeves

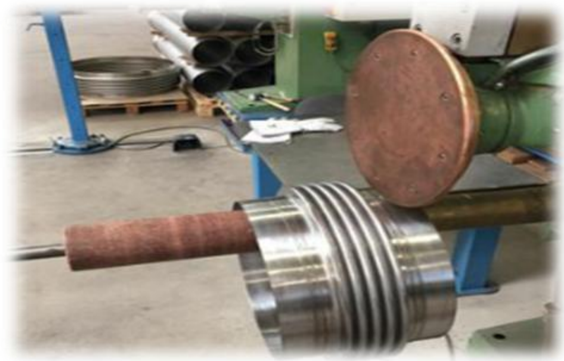
In the context of bellow fabrication, inner sleevesrefer to a protective liner or insertthat is placed inside the bellow. The inner sleeve is often made from a stronger or more resistant material than the outer layer of the bellow and serves to provide additional support, protection, and durability to the bellow’s internal structure.

An inner sleeve in bellow fabrication is a protective liningor reinforcement that is installed inside the bellow to enhance its performance, provide structural support, prevent damage, and extend its lifespan. These sleeves are typically made from materials like stainless steel, alloys, or high-strength polymers, depending on the application and the type of bellow being fabricated.

Inner sleeves

3.8 Resistance seam welding

Resistance seam welding is a typeof welding process commonly used in bellow fabrication to create a continuous, strong bond along the seams of the bellow, typically in the longitudinal direction. This method uses electric resistanceto generate heat, which is then applied to the edges of the material to fuse them together, forming a seamless, durable connection.



Resistance seam welding machine

Resistance seam welding is a process where electrical resistance is used to generate heat at the interface between two overlapping metal edges.The heat softens the metal at the contact points, and pressure is applied to weld the edges together, creating a continuous, strong seam along the length of the bellow. This process is commonly used to join the rolled edges of a sheet or strip to form the cylindrical or tubular structure of the bellow.

Bellow

4. EXPERIMENTAL INVESTIGATION OF MECHANICAL PROPERTIES

IMPACT TEST BY USING CHARPY METHOD
Charpy Test
MILD STEEL
Calculations:
1 Division value =2Joules
Length of work piece = 55mm
Breadth of work piece = 10mm
Depth of work piece = 10mm
Area of Work piece = 10*10= 100mm²
Initial Energy with work piece (E1) = 0
Energy absorbedfor pendulum specimen (E2) = 124J
= E2 – E1/A
= 124-0/100
= 1.24 J
STAINLESS STEEL
Calculations:
1 Division value =2Joules
Length of work piece = 55mm
Breadth of work piece = 10mm
Depth of work piece = 10mm
Area of Work piece = 10*10 = 100 mm²
Initial Energy with work piece (E1) = 0
Energy absorbed for specimen (E2) = 68.33 J

= E2 – E1/A
= 68.33-0/100
= 0.6833 J

Brinell Hardness test

Calculations:
Where
HB = Brinell hardness number (kgf/mm²)
P = applied load in kilogram-force (kgf)
D = diameter of indenter (mm)
d = diameter of indentation (mm)
F= Force
BHN = 2F/πD (D - √D² – d²)

TABLE: Brinell Hardness Test of Mild Steel Specimen

S.NO	STEEL INDENTOR INCH DIAMETER	LOAD APPLIED Kgf	DIA OF BALL (mm)	DIA OF IMPRESSION (mm)	B.H.N
1	1/8	500	8	6	14.69
2	1/8	500	8	5.6	17.39
3	1/8	500	8	4.8	24.86
4	1/8	500	8	4.2	33.40

Force = load*gravity

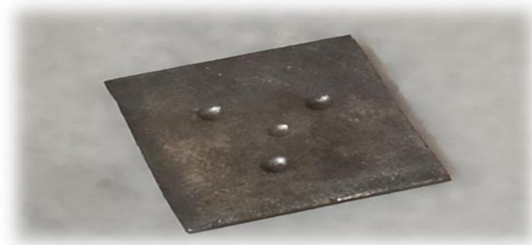
=500*9.81

=4905N

BHN = 2F/ πD (D - √D² – d²)

= 2(4905)/ (π) (8) (9.81) (8- √8² – 4.2²)

= 33.40 N/mm²



Mild Steel Specimen

TABLE: Brinell Hardness Test of Stainless steel Specimen

S.NO	STEEL INDENTOR INCH DIAMETER	LOAD APPLIED Kgf	DIA OF BALL (mm)	DIA OF IMPRESSION (mm)	B.H.N
1	1/8	500	8	5.8	15.97
2	1/8	500	8	4.2	30.17
3	1/8	500	8	4.6	27.35
4	1/8	500	8	4.1	35.19

Force = load*gravity

=500*9.81

=4905N

BHN = 2F/ πD (D - √D² – d²)

= 2(4905)/ (π) (8) (9.81) (8- √8² – 4.1²)

= 35.19 N/mm²

Compression Test on UTM

TABLE: Compression Test of Mildsteel Specimen

S.NO	LOAD (KN)	ELONGATION (mm)	STRESS N/mm^2	STRAIN
1	125	0.312	1.082	0.0035
2	250	0.632	2.210	0.0071
3	375	0.950	3.315	0.0107
4	500	1.264	4.420	0.0142
5	625	1.582	5.520	0.0178
6	750	1.901	6.631	0.0214
7	875	2.218	7.737	0.0250
8	1000	2.536	8.841	0.0285

Calculations:

Length of specimen (L) = 89 mm

Breadth of Specimen (B) = 42 mm

Area of Specimen (A) = LxB

= 89x42

= 3738 mm²

(σ)= W/A

= 125000/3738

= 33.44MPa

TABLE: Compression Test of Stainless steel Specimen

S.NO	LOAD (KN)	ELONGATION (mm)	STRESS (N/mm^2)	STRAIN
1	100	0.20	25	0.0020

2	300	0.50	75	0.0050
3	500	0.80	125	0.0080
4	700	1.30	175	0.0130
5	900	1.90	225	0.0190
6	1100	2.60	275	0.0260
7	1300	3.50	325	0.0350
8	1500	4.70	375	0.0470

Calculations:

Length of specimen (L) = 89 mm

Breadth of Specimen (B) = 42 mm

Area of Specimen (A) = LxB

= 89x42

= 3738 mm²

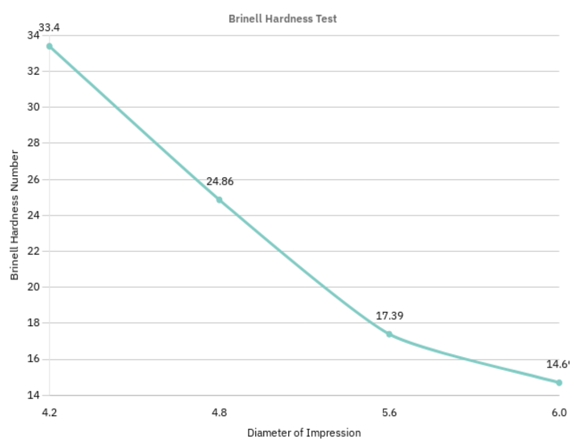
(6) = W/A

=300000/3738

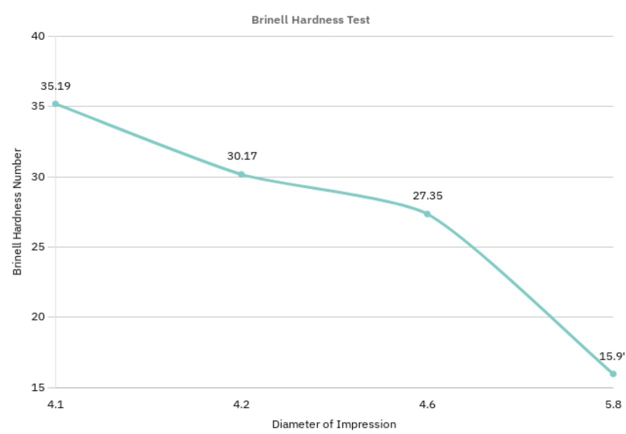
= 80.25 MPa

5. RESULT AND DISCUSSION

S.no	Test	Impact Energy Mild Steel (J)	Impact Energy Stainless Steel (J)
1	Charpy test	1.24	0.68
2	Izod test	1.64	0.75
S.no	Test	Mild Steel (BHN)	Stainless Steel (BHN)
1	Brinell hardness test	33.42	35.19
S.no	Test	Mild steel (MPa)	Stainless steel (MPa)
1	(U.T.M) compression test	33.44	80

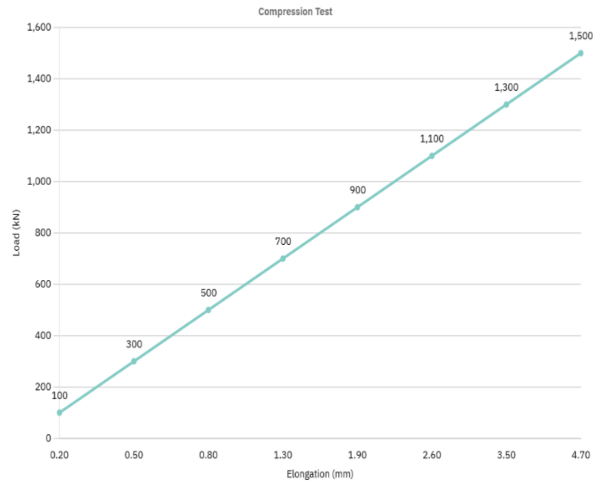


Mild steel Specimen

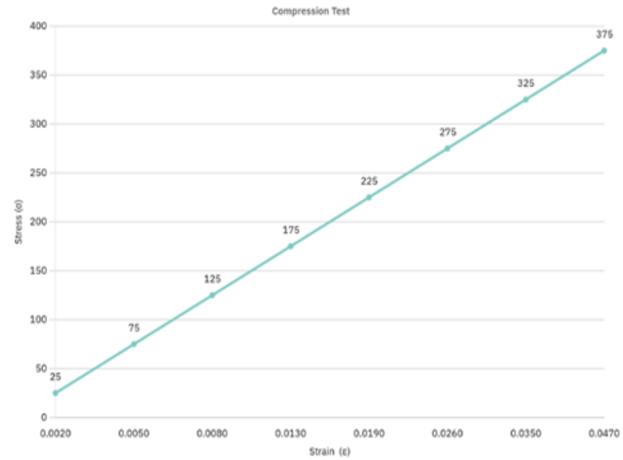


Stainless steel Specimen

Compression Test on Stainless steel Specimen



Load vs Elongation



Stress vs Strain

6. CONCLUSION

1: From the impact test Charpy it has been concluded that stain less steel 0.68 J has lower impact strength compared to mild steel 1.24J.
2. From the Izod impact test it has been concluded that stain less steel 0.75 J has less impact strength compared to mild steel 1.64 J.
3: Brinell Hardness number of Stainless steel 35.19 BHN which is more than hardness number 33.42 BHN of mild steel and hence stainless steel is better when compared to mild steel for bellow applications.
4: Compression strength of Stainless steel 80.25 Mpa compared to mildsteel 33.44 Mpa and hence stainless steel is better choice of material for bellows.

7. REFERENCE

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