STRETCH FLANGEABILITY OF ALUMINIUM ALLOYS IN CIRCULAR AND SQUARE HOLE FLANGING PROCESSES

ABSTRACT

The growing emphasis on fuel efficiency and environmental sustainability has significantly propelled the demand for lightweight materials in the automotive industry. Aluminium alloys, known for their high strength-to-weight ratio, have a high potential for replacing steel in manufacturing various sheet metal parts for automotives. However, formability of aluminium alloys is a critical factor in the success of sheet metal forming operations. In the assessment of formability of sheet metals, stretch flangeability is an important aspect. The stretch flangeability refers to the local edge formability to avoid cracking during the expansion of a hole in a sheet metal part to form a flange. It is evaluated by determination of hole expansion ratio (HER), which is the ratio of final hole diameter to initial hole diameter in a hole expansion test and it is a measure of the local formability at the edge of the hole. Besides the material properties, hole making method also influences the stretch flangeability of sheet metals. While the stretch flangeability of steels has been well reported, it has been studied only to a very limited extent in the case of aluminium alloys. In view of this, the present work is aimed at an investigation into the hole expansion test and stretch flanging processes, particularly focusing on aluminium alloys of different grades and comparing their performance with steels.

In the first part of the work, stretch flangeability of five different aluminium alloys (AA2024, AA5083, AA5754, AA6061 and AA7075) and two grades of steel (DP600 steel and EDD Steel) has been investigated by numerical simulation of the hole expansion test (HET) along with characterisation of their tensile properties, anisotropy and forming limits. The HET experiments were carried out on a customised formability testing machine to validate the predicted hole expansion ratio, and strain and thinning at failure. It has been found that AA5754 and AA6061 exhibited the highest hole expansion ratio (HER≈67%) among the Al alloys studied in the present work and it is significantly higher than that of DP600 steel also. AA2024 and AA5083 also exhibited higher stretch flangeability than DP600 steel in HET making these four alloys potentially suitable for lightweighting of sheet metals parts involving stretch flanging operations.

The quality of the hole edge plays a major role in the determination of stretch flangeability of sheet metals. Therefore, the effect of hole making method on HER has been studied in the second part of the work by preparing the samples using three different hole making methods (punching, abrasive waterjet cutting and laser cutting) from two aluminium alloys (AA5083 and AA5754) and DP600 steel. A hydro-pneumatic press along with a suitable die assembly has been developed for punching the holes. The hole edge quality has been found to be very high in laser cut samples resulting in the highest HER in all the three materials. An improvement of 36.8% and 22.5% has been obtained with laser cutting when compared to punching in the case of AA5083 and AA5754, respectively. Though WJC produced a better-quality hole edge than punching, the presence of a small notch resulted in early cracking resulting in lower HER when compared to laser cutting. However, in the case of DP600 steel, WJC resulted in a much higher improvement. In punched holes, presence of voids and microcracks and work hardening due to plastic deformation caused lower HER.

In the actual manufacturing of sheet metal parts involving stretch flanging, circular hole flanging and square hole flanging processes are commonly used. Therefore, in the third part of the work, stretch flangeability of Al alloys has been investigated in circular hole flanging and square hole flanging processes by numerical simulation and experimental validation and the results of formability, strain distribution, thinning and flange height are compared with steels. Among the aluminium alloys, AA5754 and AA5083 alloys showed highest formability in circular hole flanging indicated by their lowest minimum hole flanging coefficient (HFC_{min}) and AA7075 exhibited the highest HFC_{min}. It has been observed that HFC_{min} of AA5754 and AA5083 alloys is nearly equal to that of DP600 steel. The final flange thickness in circular hole flanging has been analytically predicted incorporating the anisotropy of sheet metals. AA5754, AA5083 and AA6061 showed better formability in square hole flanging process as indicated by their HFC_{min} values which are lower than or equal to that of DP600 steel. But in general, all the materials showed lower formability in square hole flanging than in circular hole flanging due to very high strain localization causing severe thinning and failure at the corners of the hole as indicated by the effective strain and thinning (%) distributions in the simulation.

It can be concluded that AA5083, AA5754 and AA6061 have high stretch flangeability in both circular hole flanging and square hole flanging processes and these alloys could be considered as potential materials to replace steel for stretch flanging applications where very high strength is not an essential requirement.

Key Words: Stretch flanging, Aluminium alloys, Lightweighting, Formability, Simulation