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Cold forging tool for gear accuracy grade improvement by a different shrink fitting method

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Abstract

The manufacturing of the gear profile by Metal Forming is widely used in industry due to its quality and production capability. Direct cold extrusion has this characteristic and with support of peripheral technologies allows the development of asymmetric parts with complex geometry and near net shape. These resources, added with the great experience of a Brazilian forging company with strong presence in the cold forging market, allowed to develop a cold extrusion process to produce spur gears using the low carbon steel alloy described as SAE 10B22. The goal of this study was to develop the whole process, precision tooling project and manufacture as well as the experimental availability of the process. The tools were manufactured with high speed steel AISI M2 having a hardness in a range from 61 up to 63 HRc. The shrink rings were manufactured using steels with more toughness, such as S1 and H13. The application of shrink rings for the prestressing of tooling was evaluated using two different methods. The first one is using conventional shrink rings with tool steel, while the second is the stripwinding concept developed by the company STRECON.

Keywords: shrink rings, gear grade, die cavity, prestressing.

1. Introduction

In recent years, the automotive sector has presented several proposals for quality improvement and efficiency increase applied to topics such as fuel consumption and transmission systems. The car manufactures have the challenging mission to reduce weight and to increase the component strength in order to meet the current strict requirements of the automotive market. In general, it is said that products may obtain greater resistance through forging technology.

To obtain precision products, cold forging has become a technology commonly used. The technological development and quality control from the beginning of the process up to the final product must be observed to obtain such progress in precision cold forging, which is connected with high quality materials and cutting edge techniques. In this article, some results obtained through precision cold forging and assistive technologies are presented.

2. Material and method

This article illustrates the comparative results between the dimension of gears produced by cold extrusion in a conventional double shrink ring tooling and a high strength shrink ring system developed by the STRECON Company. The forged product is a pinion for the starter drive in SAE 10B22 grade steel which is more often used in the automotive market. This is a nine-tooth pinion with normal module 2.11 and pressure angle equal to 12º. The lead length is 8 mm as Figure 1 shows. The tools are shown in Figure 2.

Figure 1
Cold extrusion pinions.

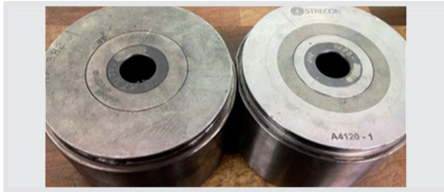

Figure 2
Cold extrusion tooling used in the experiments. Normal shrink rings (left). STRECON system (right).

Table 1 shows the chemical composition for SAE 10B22 steel.

Table 1
Chemical composition for SAE 10B22 steel (KRAUSS, 2005).

	C	*Mn*	*P*	*S*	*B*
10B22	0.18 – 0.23	0.70 – 1.00	máx. 0.030	máx. 0.050	0.0005–0.003

The yield strength (k_f) for SAE 10B22 is 302 MPa. The normal shrink ring tool has two stress rings made in steel grades S1 and H13, which are the inner and outer ring respectively. The interference fit is 0.3 mm for the inner ring and die. For the inner and outer ring, the interference fit is 0.25 mm. The average hardness was in the range of 56-58 HRc and 46-48 HRc, respectively. The yield strength for S1 is 2,150 MPa and for H13 is 1,380 MPa, for such hardness. The yield strength for high speed steel M2 applied in the dies is 3,250 MPa.

The gear errors parameters were measured in 3D machine by the software *Quindos* Gear. They are described bellow.

$f_{H\alpha}$=profile slope deviation; $f_{f\alpha}$=profile form deviation; $F\alpha$=total profile deviation; $f_{H\beta}$=helix slope deviation; $f_{f\beta}$=helix form deviation; F_β=total helix deviation; f_{pt}=single pitch deviation; F_p=cumulative pitch deviation; F_r=radial runout; Q=gear accuracy grade.

3. Results

Therefore, the chosen methodology for data acquisition was the measurement of each tooth flank for both right and left sides. The gear accuracy grade was evaluated according to the greater numeric result in a group of four consecutive flanks. The gear flank deviations for the die cavity are shown in Tables 2 and 3.

Table 2: Gear flank deviations and accuracy grade of die cavity assembled in a tool with normal shrink ring.

			left						Right			
Q	9	Q	8,7,6,5	Q	4,3,2,1	TOOTH	1,2,3,4	Q	5,6,7,8	Q	9	Q
	X(μm)		X(μm)		X(μm)	DEVIATION	X(μm)		X(μm)		X(μm	
9	14.1	10	18.4	11	31.4	$f_{H\alpha}$	21.1	10	19.7	10	10.9	8
8	13.7	8	17.6	10	29.7	F_α	20.9	9	20.6	9	12.9	7
2	1.4	6	6.3	6	5.0	$f_{f\alpha}$	4.4	5	3.7	5	2.6	4
8	9.5	8	10.2	9	16.4	$f_{H\beta}$	9.9	8	16.6	9	13.8	9
7	9.9	7	8.8	8	16.9	F_β	10.5	7	17.3	9	13.5	8
2	1.2	4	2.4	4	2.4	$f_{f\beta}$	2.5	4	1.5	2	0.9	1
		10	23.0			f_{pt}			23.8	10		
		11	68.7			F_p			63.7	10		
		10	52.4			F^*_r						

Table 3: Gear flank deviations and accuracy grade of die cavity assembled in a tool with STRECON container.

			left						right			
Q	9	Q	8,7,6,5	Q	4,3,2,1	TOOTH	1,2,3,4	Q	5,6,7,8	Q	9	Q
	X(μm)		X(μm)		X(μm)	DEVIATION	X(μm)		X(μm)		X(μm	
0	0.7	8	11.1	6	5.2	$f_{H\alpha}$	12.8	9	12.0	8	13.0	9
2	2.0	7	11.3	6	8.7	F_α	12.4	7	11.6	7	12.3	7
3	2.2	4	2.9	5	4.9	$f_{f\alpha}$	2.5	4	2.4	3	1.2	1
1	1.0	5	3.1	6	5.1	$f_{H\beta}$	2.3	4	3.8	5	0.5	0
3	2.3	4	3.8	5	4.9	F_β	3.7	4	5.4	5	0.9	0
3	1.8	2	1.3	3	1.8	$f_{f\beta}$	1.5	2	1.5	3	0.7	0
		7	8.9			f_{pt}		8.7		7		
		7	21.4			F_p		19.5		7		
		7	16.4			F^*_r						

According to ISO 1328-1, the lower the gear accuracy grade, the better will be the accuracy of the involute profile. Thus, through the results in the Tables 2 and 3, it is possible to check the gain on tool quality with the usage of the STRECON system. Both tools were tested in an eccentric press with 300-ton force. Tables 4 and 5 show the results of one sample produced by each tool.

Table 4: Gear flank deviations and accuracy grade of a forged pinion produced by normal shrink rings tool.

			left						right			
Q	9	Q	8,7,6,5	Q	4,3,2,1	TOOTH	1,2,3,4	Q	5,6,7,8	Q	9	Q
	X(μm)		X(μm)		X(μm)	DEVIATION	X(μm)		X(μm)		X(μm	
9	13.5	10	18.1	10	19.1	$f_{H\alpha}$	20.0	10	21.4	10	20.4	10
9	23.2	10	27.7	10	27.0	F_{α}	26.6	10	24.3	9	27.8	10
9	16.6	9	16.0	9	18.2	$f_{f\alpha}$	18.2	9	11.9	8	16.1	9
5	3,3	5	4.2	6	4.6	$f_{H\beta}$	5.7	6	5.7	6	3.5	5
6	6,2	8	13.5	7	11.7	F_{β}	13.3	8	24.3	7	7.0	6
6	4,3	8	11.6	8	9.0	$f_{f\beta}$	12.6	9	11.9	8	5.2	6
		8	10.4			f_{pt}			11.0	8		
		6	13.2			F_{p}			11.0	5		
		9	29.7			F^*_{r}						

Table 5: Gear flank deviations and accuracy grade of forged pinion produced by the STRECON tool.

			left						right			
Q	9	Q	8,7,6,5	Q	4,3,2,1	TOOTH	1,2,3,4	Q	5,6,7,8	Q	9	Q
	X(μm)		X(μm)		X(μm)	DEVIATION	X(μm)		X(μm)		X(μm	
9	14.8	10	23.4	10	20.5	$f_{H\alpha}$	24.4	11	24.1	11	20.5	9
9	22.4	10	28.5	10	27.1	F_{α}	32.2	10	28.7	10	25.1	9
8	13.7	8	11.1	8	11.8	$f_{f\alpha}$	11.6	8	11.4	8	11.6	9
2	1,1	3	1.6	2	1.1	$f_{H\beta}$	2.1	3	2.0	3	1.4	5
4	3,8	7	11.2	6	8.2	F_{β}	12.6	8	8.6	7	3.2	6
4	2,7	8	11.0	8	8.5	$f_{f\beta}$	11.9	8	9.6	8	3.1	6
		5	4.6			f_{pt}			3.5	4		
		3	5.0			F_{p}			5.7	4		
		6	9.1			F^*_{r}						

4. Discussion

The tendencies in precision forging such as net shape forging of increasingly complex parts according to Osakada and Tekkaya (2007), ecological manufacturing, and cold forging of stainless steel and light-weight materials lead to steadily increasing tool loads. Among the several measures to improve the tool performance and service life (Lange *et al.*, 1992), the prestressing of the forging dies is one key design parameter. The importance of prestressing increases with the tool load. The higher the forming load, the higher the level of tensile stresses in the forging die according to Groenbaek and Hinsel (2000).

A more developed approach to prestressing is to look at the stress / strain behavior of the forging die. This approach examines the full load cycle of the forging die including the stress range and the physical movement of the forging die (i.e. strain behavior). As shown in Figure 3, the pole position of the forging die will be at a certain level of compressive stress, which is determined by the interference fit.

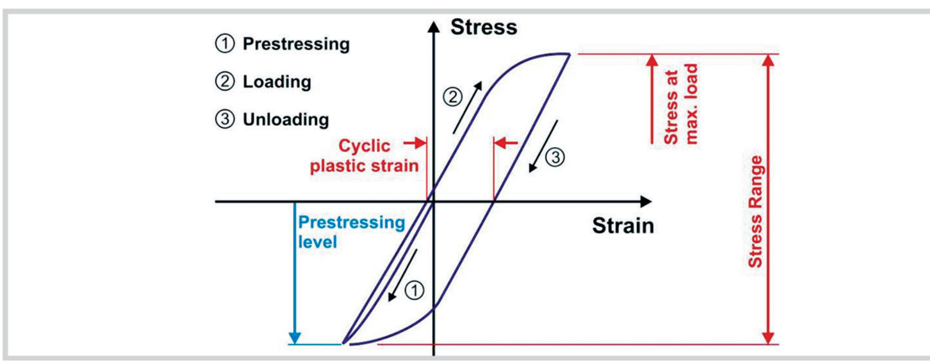

Figure 3
Principal stress-strain response in the critical point of a prestressed forging die.

In principle, prestressing can be performed by two generic and mutually different methods as shown in Figure 4. One method is prestressing by heat shrinkage, in which the shrink ring is being enlarged by preheating, for example at 400°C (Brecher *et al.*, 2008). Another method is prestressing by press fitting where the forging die is pushed into the shrink ring by means of a tool assembly press. It depends on parameters as the size of the forging die and the level of interference fit (Engel and Geiger, 2008):

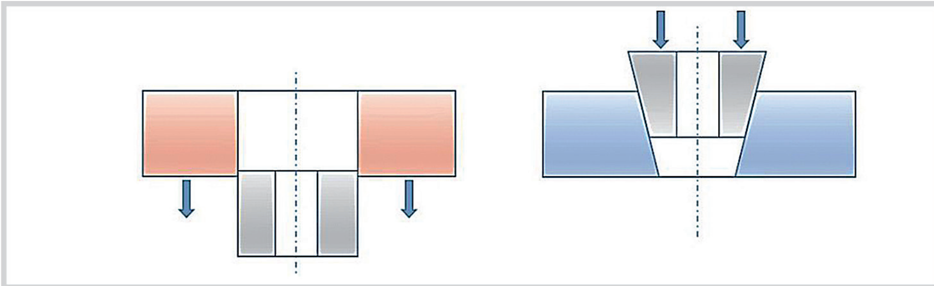

Figure 4
Principle method of prestressing by heat shrinkage (left) and by press fitting (right).

An alternative approach to obtain high-stiffness forging tools would be to integrate the tungsten carbide material as part of the prestressing system, for example by having the inner ring of the double ring system made of tungsten carbide (Lund and Andresen, 2015) or to use a technology developed by the STRECON Company. Figure 5 shows an example in a cut-view of the concept of STRECON containers.

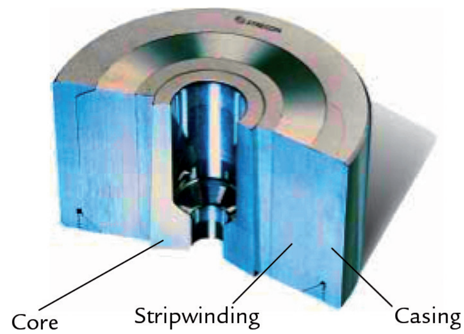

Figure 5
Example of STRECON container.

A shrink ring made by the stripwinding technique offers a prestressing tool system stronger than the standard shrink rings.

5. Conclusions

The results in Tables 4 and 5 showed a significant difference between the quality of die cavity and their cold forged product. The residual stresses and tool elastic deformation, which applies a plastic deformation on a forged product, are some of the main points that affect the gear accuracy grade of the pinion.

According to the results, it is possible to check that all the deviations of the forged products showed dimensional scatter regarding the results found in their respective dies. Individually, the die assembled in the STRECON container presented profile, helix, pitch and runout deviations lower than the die with normal shrink rings. Therefore, it means a more precise gear accuracy grade.

The cold forged pinions produced by both tooling systems showed similar profile deviation. However, helix, pitch and runout deviation had better performance for pinions produced by the STRECON container die. The gear accuracy grade was more effective for these deviations.

Electrical Discharge Machining technology will be the scope of new researches about die cavity manufacturing. The expectation is refining geometry of gear flank, and thus reducing their dimensional scatter, can provide high gear accuracy grade in cold forged products such like those obtained by some specific machining processes.

Acknowledgements

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