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THE INFLUENCE OF CHEMICAL COMPOSITION ON MECHANICAL PROPRETIES OF FLOW FORMED STEEL TUBES

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Abstract:*The influence of chemical composition on mechanical properties of flow formed tubes were examined. Two medium carbon steels, 41Cr4 and 42CrMo4were used. Flow forming was performed on industrial equipment in two passes, with totalreduction of 75%.Strain hardening was evaluated by means of strength, elongation andhardness.*
For both steels, yield strength increased from initial 756 MPa and 751 MPa to1197 MPa and 1032 MPa, for 41Cr4 and 42CrMo4 steels, respectively, while ultimate tensile strength increasedfrom initial 908 MPaand 857 MPa on 1308 MPa and 1210 MPa. Hardness, as illustration of strain hardening also increased from initial 275 HB and 274 HB to 380 HB and 362 HB,respectively.In both steels, elongation is greater than12%, indicatingthat during flow forming,together with strain hardening, a restoration of deformed microstructure also occurred. Sinceapplied flow forming is cold deformation process, it is assumed that dynamic recovery occurred during flow forming.

Keywords:*flow forming, tube,41Cr4 steel, 42CrMo4steel.*

1. INTRODUCTION

Flow forming is the most superior process of obtaining thin wall tubes with ratio length/diameter>10 and diameter/wall thickness >50[1-3]. In this process preform, the most often cup or tube, is formed into hollowcylinder with the wall thickness reduction. The metal is displaced axially along a mandrel, increasing the length of the workpiece, while the internal diameter remains constant (Figure 1).

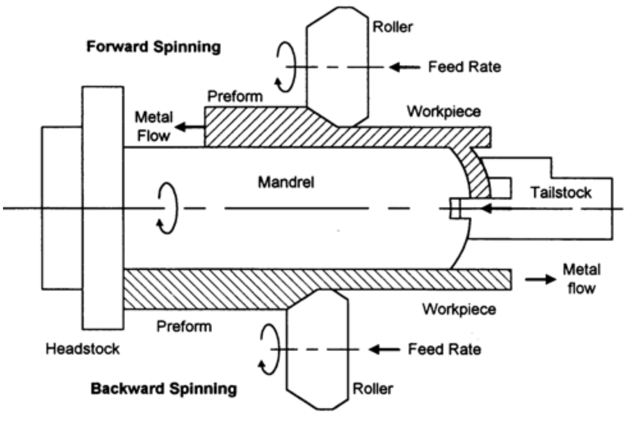


Figure 1. Forwardand backward flow forming (tube spinning) [1].

Flow forming has significant advantages in comparison to conventional production technique, such as: high dimensional accuracy, qualityof inner element surface, low tools price, high processrate, material savings, increasing in both strength andstiffness, etc. [1-3].
Among many factors that influence theprocess, the most important are selection of the type ofsteel and optimal heat treatment of the preform, partial and total deformation and gap betweenmandrel and preform [3-8]. Quality of the flow formed tubes is also influenced by design and dimension of the rollers,position during the forming, mandrel speed and axialroller feed rate[9].

Flow forming is suitable to deform large number of materials, soft materials, suchas aluminum and copper, medium and very hard materials, even difficult-to-form metals be flow formed.

The aim of this work was to examine the influence of chemical composition on mechanical properties flow formed tubes, as well as strain hardening during the flow forming process.

2. EXPERIMENTAL

2.1.Material

Two medium carbon steels, 41Cr4 and 42CrMo4 were used, according to SRPS EN 10083-3 and SRPS EN 10083-3, respectively.

The chemical composition of used steel are given in Table 1.

Table 1.The chemical composition of the steels, mass. %

Steel	**C**	**Cr**	**Si**	**Mn**	**P**	**S**	V	Mo
41Cr4	0,406	1,009	0,131	0,660	0,014	0,004	/	/
42CrMo4	0,420	1,000	0,200	0,800	0,011	0,003	0,13	0,21

2.2. Flow forming

The sketch of preform for flow forming is given in Fig.2. It was made of hot rolled seamless steel tubes after machining and heat treatment.

The dimension and temper of hot rolled tubes are given in Table 2.

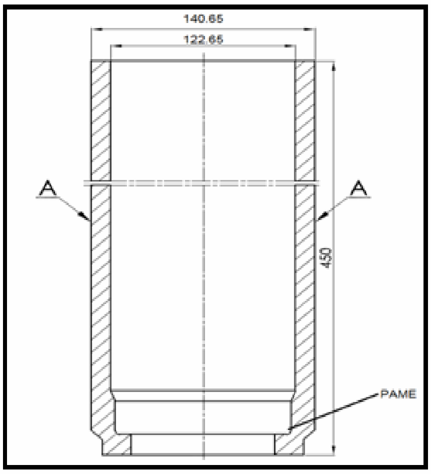


Figure 2. Preform for flow forming.

Table 2. Tubes dimension and temper

Steel	Hot rolled tube		Temper
	D_{out}(mm)	δ (mm)	
41Cr4	139	16	A
42CrMo4	127	17.5	Q+T

A-anneled

Q+T –quenched+tempered

The preforms for flow forming of41Cr4 steel was procced by:

- machining
- heat treatment Q+T
  HT1: 840°C/3,5h/oil +600°C/4,5 h /air,or
  HT2: 830°C/3.5 h/water +580°C/ 4,5h /air,
- final machining.

The preform of 42CrMo4 steel was produced by machining.

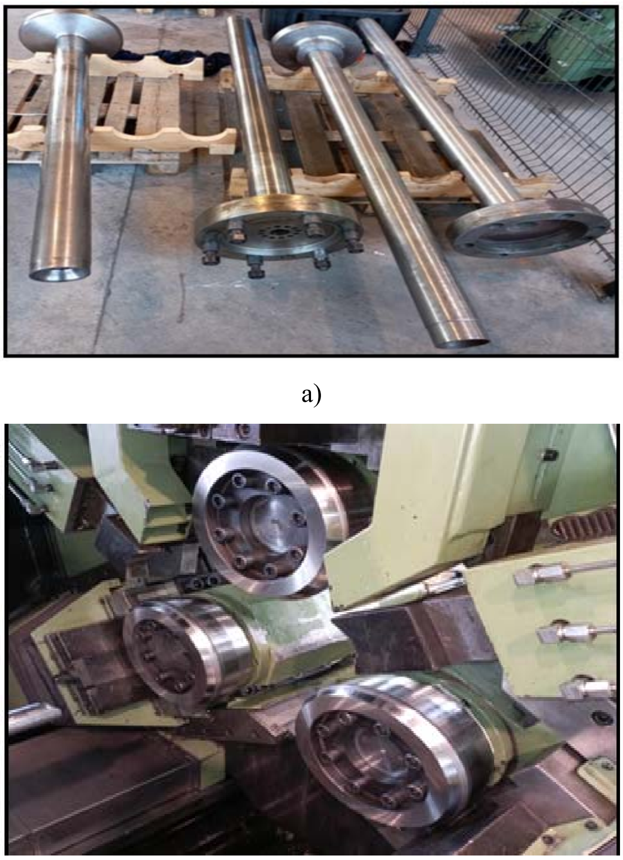
Forward flow forming was performed using LEIFELD ST 56-90 CNC - 10/1machine, with three rollers.Tools, mandrel and rollers (Figure 3) were made of high qualitytool steel and polished.

Preforms of both steels processed in twopasses:

– from 9.0 mm up to 5,5 mm, and

– from 5.5 mm up to 2.2 mm,

where total reduction was 75 %. Mandrel speed was 270 rpm, and axialroller feed rate 300 mm/min.



a)

b)

Figure 3. Mandrels (a) and rollers (b) for flow forming.

2.3. Stress relieving

After flow forming, up to 4 hours after forming, stress relieving was performed at 280°C/5h/furnace cooling (5˚C/min).EKPKCPH 200/300 furnace was used. Tubes are placed on vertical supports.

2.4. Testing methods

Visual examination, hydrostatic test and magnetic particle inspection were performed, as well as mechanical properties testing.

Hydrostattic test performed on 100 % specimens on SERVOTEHhydroequipment.
Ferromagnetic particle inspection performed on FEROFLUX UNIVERSAL SW 3200 used.

Mechanical properties were determined by tensile tests and hardnessmeasurement.

Brinell hardness measurement HB 2,5/187,5/15, according to SRPS EN ISO 6506-1, performed on SENSUS HBT-01 (Figure 3). Prepared tubes are fixed on support. Software SENSUSVMT-BHT used.

Tensile tests were carriedat room temperature onWOLPERT 10-TUZ-745-100kN testing machines, using proportional squared specimens (d=15 mm, b=2,2 mm, L_0=62mm), according to SRPS EN ISO 6892-1.3. Three specimens were cut from each tube, at 120°.

3. RESULTS

The results of mechanical testing of the preforms are given in Table 3.

Table 3. Mechanical properties of the preforms

Steel	$R_{p0.2}$[N/mm^2]	R_m[N/mm^2]	A_5 [%]	HB
41Cr4	756	905	18,30	275
42CrMo4	751	857	20,00	274

Non-destructive tests performed on the flow formed tubes, visual examination, hydrostatic test and magnetic particle inspection, did not show presence of the defects for both steels.

The results of mechanical testing of the flow formed tubes are shown in Table 4.

Table 4. Mechanical properties of the flow formed tubes

Steel	$R_{p0.2}$[N/mm^2]	R_m[N/mm^2]	A_5 [%]	HB
41Cr4	1197	1308	12.8	380
42CrMo4	1032	1210	15,3	362

Mechanical properties of the preforms of both steels are similar. After flow forming, hardness and strength of the tubes increase with increasing strain, and more intensive increase was obtained for 41Cr4 steel (Figures 4 and 5).

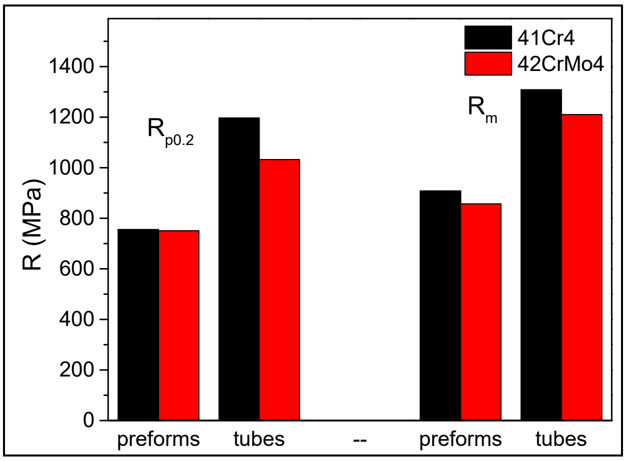


Figure 4. Effect of strain on $R_{p0.2}$ andR_m of flow formed 41Cr4 and 42CrMo4 steels.

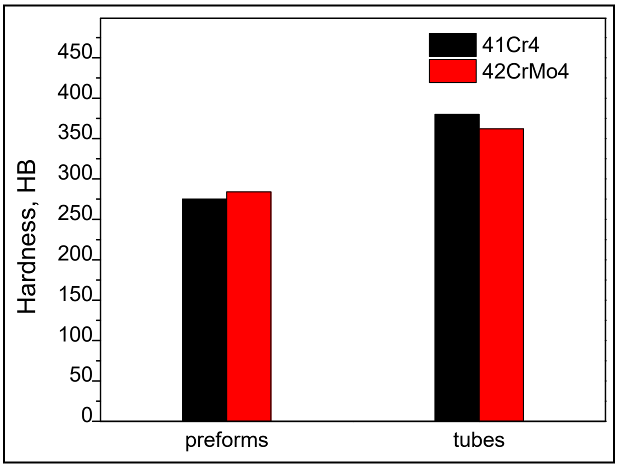


Figure 5. Effect of strain on hardness of flow formed 41Cr4 and 42CrMo4 steels.

4. DISCUSSION

During cold flow forming, it is expected that increase of dislocation density leads to strain hardening. Both steels were deformed in tempered state, i.e. starting microstructure consisted of tempered martensite with carbides (dominantly chromium carbides). It can be assumed that presence of Mo increases hardenability and increases the amount of martensite, i.e. carbon supersaturation will be higher. Therefore, driving force for precipitation will be increased, leading to, dominantly, higher nucleation rate for precipitation. Precipitation will start on grain boundaries, dislocation and twins formed during martensite transformation. Final result is that preforms made of CrMoV steel will have smaller precipitates on shorter distances.
The start of deformation is characterized with reactions of dislocations with coherent particles. Since particles are expected to be coherent in both steels, their response to applied stress,i.e. yield stress of both preforms/steels have similar values[10-12].

Flow forming technology was invented with aim to overcome very limited plasticity, since in uniaxial testing, plastic instability – necking appears at very smal elongation. Introduction of additional compressive stresses due to use of mandrel and roller, provided delay of necking to considerably larger strains. The key is in presence of dynamic recovery. In this proces, in dynamic conditions, present dislocations do not change their density, but only their distribution, i.e. large number of dislocations will be re-grouped to subgrain baundaries during deformation[10-12].

After flow forming, Yield stress and UTS of 41Cr4 steel have higher values in comparison to 42CrMoV4 steel. Higher strength means that higher dislocation density is present. It can be assumed that carbides in 41Cr4 steel are larger than in 42CrMo4 steel and that some of them are not only coherent, but also semi-coherent. This difference has two consequences: (i) longer distance between carbides and (ii) additional hardening due to formation of Orowan loops [13]. Both consequences lead to much pronounced dislocation reactions and final higher dislocation densities. In this respect, steel 41Cr4 exhibits higher strain hardening rate which lead to higher value of UTS. These results are in good agreement with previouslypublished results on similar steels [4].

5. CONCLUSION

The influence of the chemical composition of the two medium carbon steels, 41Cr4 and 42CrMo4, on strain hardening of flow formed tubes was examined.Used steels contain 0.41 %C and 1 % Cr, with addition of 0.2 % Mo in 42CrMo4 steel. Hot rolled tubes after heat treatment and machining used as the preforms. The flow forming performed in two passes with total reduction of 75 %.

The non-destructive testing did not revealed the presence of defects, and hydrostatic test did not cause the occurrence of excessive dilatations.

After flow forming both steels exhibit large strain hardening. It was established that the yield strength increasedfrom 756 MPa and 751MPa, to 1197 MPa and 1032MPa,for41Cr4 and 42CrMo4 steels respectively, while tensile strength increasedfrom 908 MPa and 857MPa to 1308 MPa and 1210MPa. At the same time, hardness increased from 275 HB and 274 HB, to 380 HB and 362 HB. Hardening was more pronounced in 42Cr4 steel. It was assumed that presence of semicoherent particles enabled Orowan hardening and increased strength.

References

[1] Wong, C.C.,Dean, T.A.,Lin, J., *A review of spinning, shear forming and flow forming processes*, International Int. J Mach Tools Manuf 43 (2003) 1419–1435.

[2] Sivanandini M., Dhami S.S., Pabla,*Flow Forming of Tubes-A Review*, International Journal of Scientific & Engineering Research, Vol.3, Issue 5, 2012.

[3] ASM metals handbook: *Forming and Forging*, Vol. 14. 9th ed. Ohio: ASMMetalsPark, 1988.

[4] Nikačević, M., Radović, Lj., *The influence of the heat treatment on the properties of flow formed rocket motor cases of 30CrMoV4 and 41Cr4 steels*, 6th Scientific Conference on Defensive Technologies, OTEH 2014, Belgrade, Serbia, 2014, 812-816.

[5] Rajan, K.M., Deshpande, P.U.,Narasimhan, K., *Effect of heat treatment of preform on the mechanical properties of flow formed AISI 4130 steel tubes - a theoretical and experimental assessment*, J Mat Proc Tech, 125-126, 2002, 503-511.

[6] Tsivoulas,D., et al., *Effects of flow forming parameters on the development of residual stresses in Cr–Mo–V steel tubes,*MatSciEngA624(2015)193–202.

[7] Podder, B.,et al., *Effect of preform heat treatment on the flow formability and mechanical properties of AISI4340 steel*, Mater Des 37 (2012) 174–181.

[8] GürC. H.,Arda, E. B., *Effect of tube spinning and subsequent heat treatments on strength, microstructure and residual stress state of AISI/SAE type 4140 steel*, Mat Sci Tech,Vol. 19, 2003,1590-1594.

[9] Jahazi, M., Ebrahimi, G., *The influence of flow forming parameters and microstructure on the quality of a D6ac steel,* J Mat Proc Tech 103 (2000) 362-366.

[10] Drobnjak, Dj., *Physics of strength and plasticity*, Faculty of Technology and Metallurgy, Belgrade, 2015.

[11] Dieter, G., *Mechanical Metallurgy*, McGraw Hill-Book Company, Si Metric ed., London, 1988.

[12] Smallman, R. E., Bishop, R.J., *Modern Physical Metallurgy and Materials Engineering*, Sixth ed. Butterworth-Heinemann, Oxford, 1999.

[13] Bhadeshia, H.K.D.H., Honeycombe, R.W.K., *Steels Microstructure and Properties,*Third edition, Elsevir, Amsterdam, 2006.