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CHARACTERISTICS OF THE NEW DEVELOPED HOT WORK TOOL STEEL FOR ALUMINUM EXTRUSION – VEX[1]

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Abstract
Aluminum extrusion dies are an important segment of industrial tools, which are manufactured in steels based on AISI H13. The main properties of steels applied to extrusion dies are: wear resistance, toughness and tempering resistance. The present work discusses the characteristics of a newly developed hot work steel to be used on aluminum extrusion dies. The effects of Cr and Mo contents with respect to tempering resistance, and the Al addition on the nitriding response have been evaluated. From forged steel bars, tests on toughness and characterization via EPMA have been conducted. The proposed contents of Cr, Mo, and Al have attributed to the new VEX grade a much better tempering resistance than H13, as well as, a deeper and harder nitrided layer. Due to the unique characteristics, this new development will provide an interesting alternative to the aluminum extrusion companies to increase their competitiveness.
Key words: Aluminum extrusion; Extrusion dies; Tool steel; Nitriding.

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1 INTRODUCTION

Aluminum extrusion dies are mainly manufactured in standardized hot work tool steel based on AISI H13. While other segments like forging and aluminum die casting had many new tool steel developments in the last ten years,(1-3) the aluminum extrusion industry continues to use H13 and DIN 1.2714 to manufacture their extrusion dies and support parts. In the past decade, the tool steel producers understood how to increase the steel's tempering resistance and toughness by the right balance of alloying content, as well as control of minor elements in their chemical composition, especially with respect to Cr, Mo and silicon (Si) contents.(1-3) Nitriding is also largely used on extrusion dies to increase the die's lifecycle. The effect of alloying elements on nitridability of hot work tool steel was also a subject of recent research.(4,5) These studies showed the effect of Al contents on the nitrided case depth and surface hardness, respectively. Thus, an opportunity of a hot work tool steel development to be exclusively used for aluminum extrusion process was given. In this paper, the comparison of results between AISI H13 and the newly-developed hot work tool steel grade VEX (Villares Extrusion) is reported.

2 EXPERIMENTAL PROCEDURES

The chemical compositions of VH13 (AISI H13 – North American Die Casting Association – NADCA, Specification 207-2006 Premium Quality)(6) and VEX (Villares Extrusion) hot work tool steels are shown in Table 1. These steels were melted in an electric-arc furnace, followed by ladle metallurgy treatment, and conventional casting. The ingots were forged into 10-inch diameter bars, and then annealed to maximum 235 HB.

Table 1. Chemical compositions of hot work tool steels VH13 and VEX; values in weight percent(7)

Steel*	AISI	DIN WNr	C	Si	Mn	Cr	Mo	V	Al
VH13	H13	1.2344	0.39	0.9	0.3	5.1	1.2	0.8	0.03
VEX	-	-	0.51	0.3	0.3	3.7	0.6	0.4	0.56

** Villares Metals trademark; VEX patent pending.*

Samples from the center of the bars were cut to perform the steels characterization. Following the NADCA standard,(6) the samples from both steels were machined and hardened to 45 HRC by quenching and double tempering.
Four main investigations have been conducted with these samples:

- Tempering resistance, which means the steel resistance to keep its hardness when exposed to high temperature during long time periods. This test was performed at 600ºC. The steel's Rockwell C hardness was measured after 1 hour, 3 hours, 10 hours, 30 hours, and 100 hours at temperature.
- The steels' nitriding response were evaluated in gas processes - Nitrex®,(8) the main nitriding parameters were temperature of 530ºC and 8.0 hours nitriding time. The furnace atmospheres (N_2 and H_2 gases contents) were selected to prevent the formation of a compound layer, which is often called white layer.
- Metallographic characterization of the nitreded steels. The main purpose of this test was to compare the obtained nitrided layer depth in VEX with H13.
- Toughness. *Charpy V* notch test specimens were cut and machined in the transverse bar direction.

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Wavelength dispersive spectroscopy (WDS) profile microanalysis was conducted in a JEOL JXA-8230 Electron Probe Micro Analyser (EPMA). The nitrided layers features were also evaluated, with respect to micro-hardness profiles. These tests were conducted based on the DIN 50190 standard.(9)

3 RESULTS AND DISCUSSION

3.1 Tempering Resistance

It has already been pointed out that new generations of hot work tool steels with better chromium and molybdenum balance in their chemical composition increase the steel's tempering resistance, as indicated by Figure 1. Note that both VH13 and VEX have an initial hardness of 45 HRC, but after 100 hours at 600ºC, VH13 hardness dropped to 29 HRC while VEX decreased only to 36 HRC. In other words, it took VH13 only 35 hours to reduce hardness by 9 HRC points, while VEX did not lose this hardness until 100 hours, which means that VEX has a tempering resistance almost three times higher than VH13. The tempering resistance is suitable way to estimate the die's loss of hardness during service. So extrusion dies manufactured in steels with higher tempering resistance will remain stronger for a longer time.

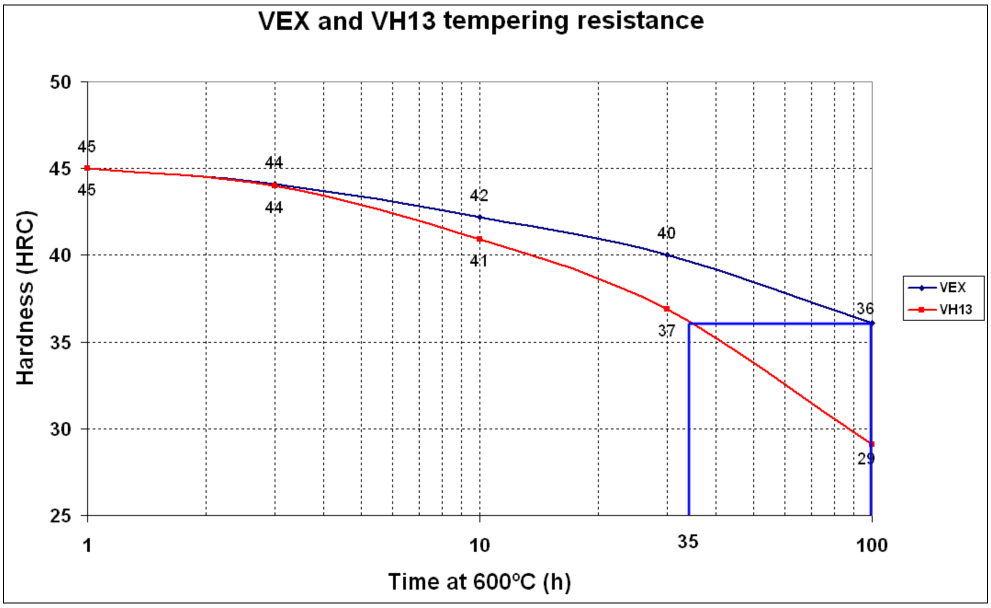

Figure 1. Tempering resistance of VH13 and VEX steels.

3.2 Nitriding Response

One way to understand the steel's nitridability is by reviewing its hardness profile after processing. Figure 2 shows VEX and VH13 hardness profiles after gas nitriding. Higher surface hardness and deeper nitrided layer was formed in VEX. Following DIN 50190, the VEX case depth was 115µm, and its surface hardness higher than 1,200HV. VH13 had a case depth of 75µm, and 1,050HV surface hardness.

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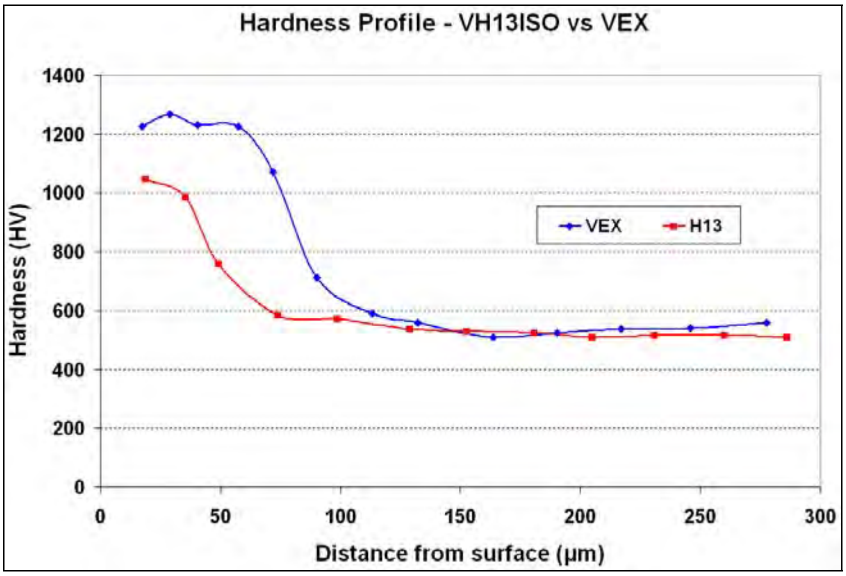

Figure 2. Hardness profiles of the gas nitrided steels.

The explanation for the deeper nitrided layer is because VEX has a lower amount of alloying elements in its chemical composition, the sum of %Si + %Cr + %Mo + %V + %Al contents in VEX is only 5.6% compared to 8.0% in VH13. Alloying elements act like obstacles or barriers to atomic nitrogen diffusion, therefore VEX has better nitridability than VH13. Moreover, it is known that silicon has a high influence on steel nitridability,[4,5] and VEX has silicon content three times lower than VH13.
On the other hand, the reason for the higher surface hardness in VEX is the change on the nitrides precipitated type during the nitriding process. In VH13 there is predominantly chromium nitride (CrN) formation, while in VEX, aluminum nitrides (AlN) seem to be preferentially formed. It is well known from the literature[10] that aluminum has more thermodynamic affinity by nitrogen, and its nitrides (AlN) are harder than CrN.
So, it is possible to expect in the new grade VEX a better die wear resistance in the aluminum extrusion process (mainly in solid dies) thanks to its good nitriding response, and a longer production run of extruded parts for each die nitriding cycle.
The WDS profiles microanalysis results are shown in Figures 3 to 5. Figure 3 shows the nitrogen profiles where it was possible to verify the significant amount of nitrogen present in both steel surfaces as already expected, because of the nitriding process. Figure 4 shows a higher presence of chromium only in VH13 surface, and Figure 4 shows the notable presence of aluminum only in VEX surface. This test was done to confirm the higher thermodynamic affinity of aluminum by nitrogen, and it leads to the conclusion that AlN precipitates are present instead of CrN in the VEX nitrided layer.

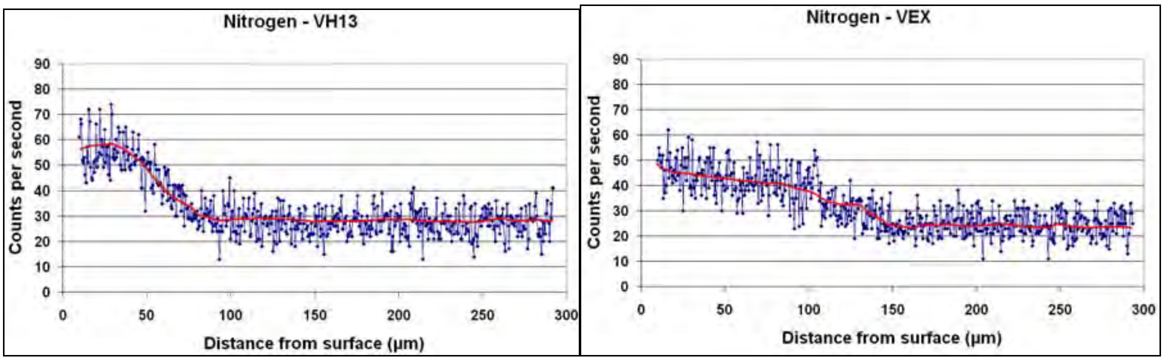

Figure 3. Nitrogen microanalysis profiles.

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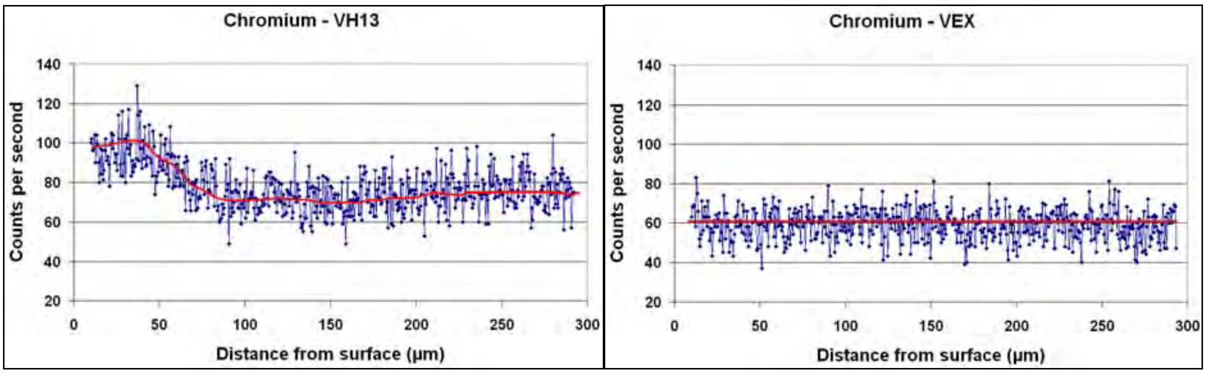

Figure 4. Chromium microanalysis profiles.

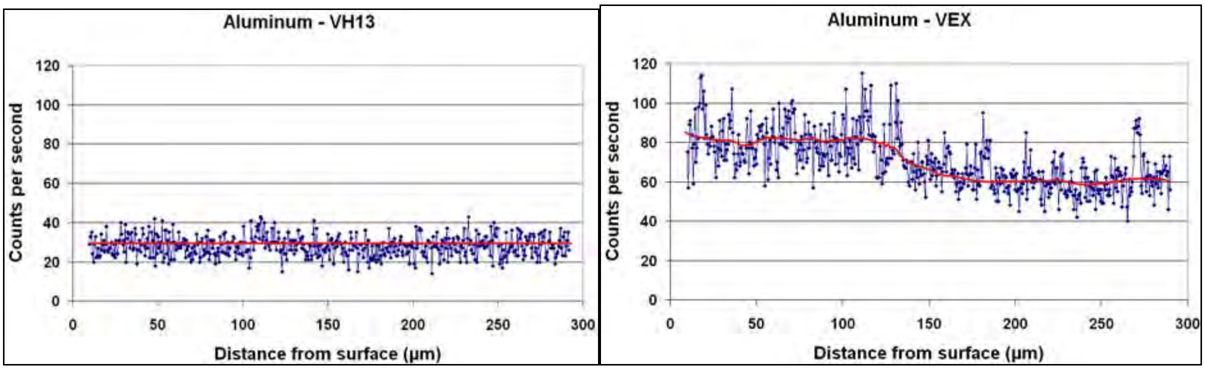

Figure 5. Aluminum microanalysis profiles.

3.3 Microstructure

The microstructure from the nitrided surface of both steels can be observed in Figure 6. Comparing the images, the deeper nitrided layer (diffusion layer) in VEX grade than in VH13 is visible. See the darker surface regions in Figures 6a and 6b, which represents the enriched nitrogen area.

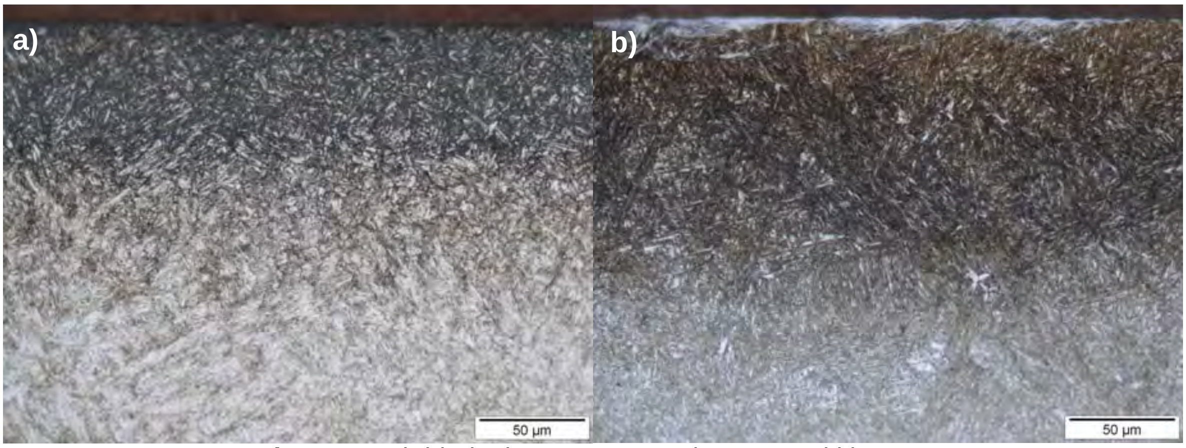

Figure 6. Nitrided microstructures: a) VH13 and b) VEX.

3.4 Toughness

The steels toughness properties, which are very important mainly regarding hollow extrusion dies, are shown in Figure 7. When compared to the Premium Quality NADCA standard [6], the minimum average of absorbed energy in Charpy V notch test is 11.0 Joules (8.0 ft.lbs), where the single minimum value of 8.0 Joules

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(6.0 ft.lbs) was exceeded. So, VEX steel is acceptable, based on these criteria, as well as H13 produced in Villares, VH13.

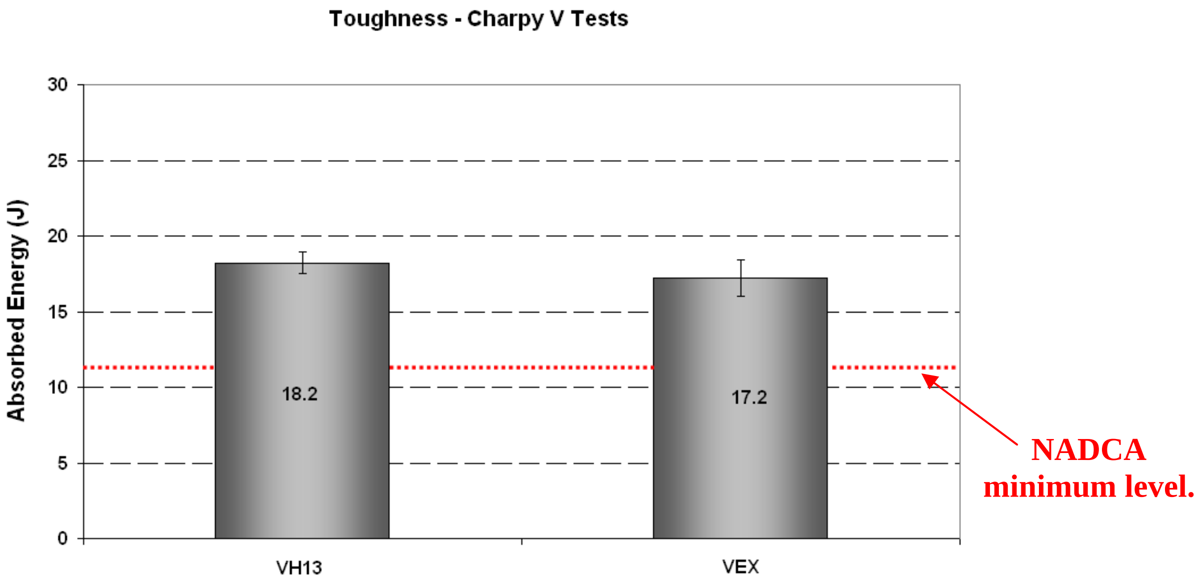

Figure 7. VEX and VH13 toughness measured by Charpy V tests as predicted in NADCA.

4 CONCLUSIONS

The right balance of Cr and Mo contents in the new VEX steel grade has attributed to the steel an excellent tempering resistance.
VEX has a deeper and harder nitrided layer than VH13, due to the lower amount of alloying elements and the addition of Al in its chemical composition.
The nitride case study has shown that the aluminum nitrides precipitates seem to be formed in the new VEX grade are harder than the chromium nitrides formed in VH13.
The presence of AlN precipitates in VEX surface after nitriding provides an interesting alternative to the materials already used by aluminum extrusion companies to increase their performance.

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