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Welded Joint Nonpenetration and Slag Inclusion Evaluation Based on MMM Signal Characteristic

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Abstract. The metal magnetic memory (MMM) technology, a new nondestructive testing (NDT), has potentials of quantitative evaluation on welded joint defects. This paper investigates MMM signal quantitative characteristic of welded joint defects. Steel Q235 welded joint specimens, prefabricated with nonpenetration and slag inclusion, have been scanned by MMM testing instrument at 0kN, 150kN and 230kN tension loads on tensile machinery. For the nonpenetration specimens, MMM peak amplitude ΔHp and the peak width D adds with the increasing of tensile load, but gradient K varies a little. As for the slag inclusion specimens, the ΔHp and K enhances along with tensile load increasing, but the D varies a little. The X-ray testing results at 0kN, 150kN and 230kN tension loads show the validity of MMM signal characteristic. This means the feasibility of the weld qualitative and quantitative evaluation based on MMM method.

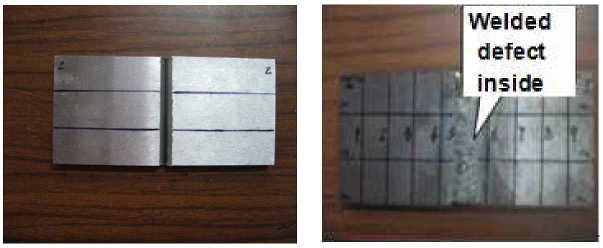
Introduction

Quantitative testing of welded joint defects plays an important role for equipment safe. Different welded joint defect does different degree harm to equipments. It is very important to discover the defects at the early stage. However, the traditional NDT can't detect early damage until macroscopic fault has been formed. A new NDT method, called magnetic metal memory (MMM) technology, can not only evaluate the early failure but also find the formed macro-defects. It was first introduced by the Russian researcher Dubov A.A. [1] on the 50th international welding conference. By testing magnetic density Hp distribution of specimen's surface, the most serious zones of stress concentration, defects and metal structure non-uniformities can be found [2]. Moreover, it does not require special magnetization devices and tested surfaces need not special treatment.

At present, MMM weld testing mainly focus on qualitative research [3~6]. Many aspects of MMM weld testing need to be further perfected, for example MMM characteristic signal comparing for different type of welded joint defects and serious degree quantitative evaluation. This paper aims at quantitative MMM signal characteristic of different welded joint defects through experiments. Steel Q235 welded joint specimens have been measured by MMM instrument at 0kN, 150kN and 230kN tension loads. By data comparing between welded joint nonpenetration and slag inclusion, are given the quantitative MMM signal rules on different load levels. The X-ray testing results show the validity of MMM signal characteristic of welded joint nonpenetration and slag inclusion, which provides the foundation for MMM quantitative evaluation on welded joint defects.

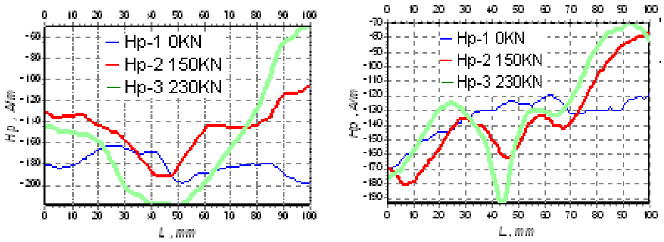
Experimental materials

Two groups of specimens are made of Steel Q235, and the welding wire is H08Mn2Si. Manual argon tungsten-arc welding is adopted. In the middle of welded joint, one group is embedded with nonpenetration and the other is embedded with slag inclusion. The specimen size is 100×45×6 mm, and the shape is shown in Fig.1.



(a) Before welded (b) After welded

Fig.1 Specimen picture

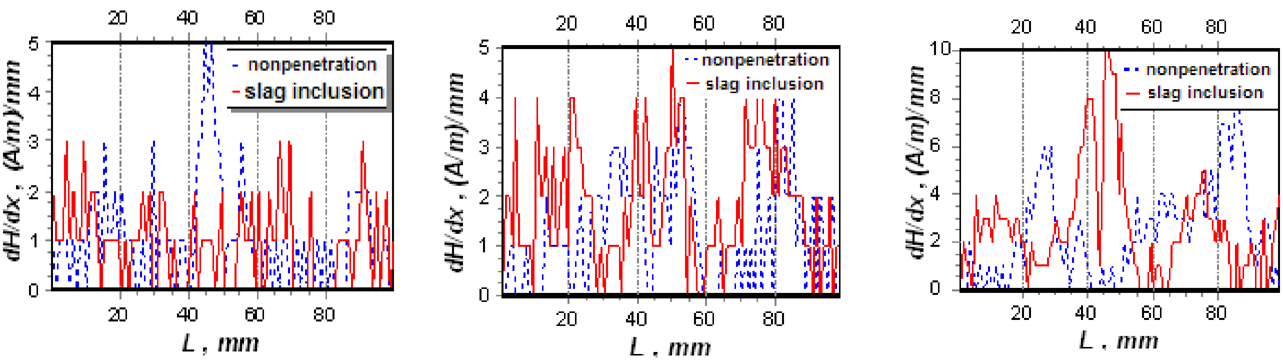


(a) Nonpenetration defects (b) Slag inclusion

Fig.2 MMM signals at different loading levels

Experimental method

The MMM scanning instrument is TSC-1M-4 which is from Russia Dynamic Diagnosis Company. The multi-function testing machine DSS-10T-S is used to provide tension loads. First the initial MMM signals are detected as the references. Then the two groups of specimens, i.e. welded joint nonpenetration and slag inclusion, are clamped in the testing machine respectively. 0kN, 150kN and 230kN tension load are applied in turn. Each level loading was retained 5 minutes, and then MMM testing is made along the longitudinal direction of the specimen.



(a) 0kN (b) 150kN (c) 230kN

Fig.3 MMM gradient K comparing between welded joint nonpenetration and slag inclusion, here, $\Delta Hp = Hp_{max} - \overline{Hp}$, ΔHp is peak, Hp_{max} is maximum of magnetic density Hp, $\overline{Hp}$ is average, D is wave width and gradient $K = dHp/dx$.

Results

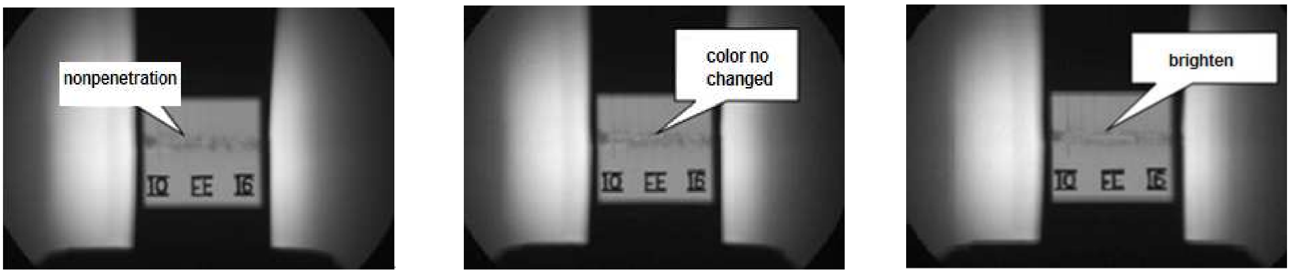
Nonpenetration. As can be seen from Fig.2(a), there is a fluctuation at 0kN load level in the center of curve Hp-1. It shows MMM characteristic signal existed in the welded joint nonpenetration zone, which shows the feasibility of MMM early defect testing. With the increasing of tension load, MMM peak amplitude ΔHp and the peak width D adds, but gradient K varies a little. When the tension load is 150kN, material stress gets to yield limit. Though macro damage doesn't appear on the surface of specimens, MMM signals changes more obviously, which the width D increases from 18mm to 35mm and ΔHp increases from 12A/m to 36A/m in Hp-2. This is because nonpenetration zone is stretched and becomes worse inside welded joint. When the load approaches to 230KN, material stress gets to ultimate strength and macro crack has become 1mm on the surface of welded joint, which ΔHp reached to 84A/m and D reached to 67mm in Hp-3. MMM waveforms became wider and wider, which correctly reflects the crack width increasing in nonpenetration zone.

Slag inclusion. The MMM results of slag inclusion specimen are shown in Fig.2(b). With the increasing of tension load, ΔHp and K enhances obviously, but the D varies a little. The fluctuations of Hp-1 weren't obvious relatively to Hp-2 and Hp-3 in Fig.2(b). But it still shows the early existing of welded joint slag inclusion. When the load reaches to 150kN, i.e. yield limit, fluctuation significantly appears at the center of specimen, which *ΔHp* changes from 24 A/m to 42 A/m. When it reaches to 230kN, i.e. ultimate strength, sharp peak of MMM curve appears on the welded joint slag inclusion zone, which *Δ Hp* increases to 61 A/m.

Contrasting nonpenetration to slag inclusion. From Fig.2(a) and (b), the width *D* is more sensitive to nonpenetration than slag inclusion at the same tension loads. In order to further compare the two welded joint defects, the gradient *K* is shown in Fig.3. The gradient *K* of nonpenetration doesn't vary obviously, which is from 5 A/m/mm at 0kN to 6 A/m/mm at 230kN. But the gradient *K* vares obviously, which is from 3 A/m/mm at 0kN to 10 A/ m/mm230kN. Therefore, the gradient *K* is more sensitive to slag inclusion than nonpenetration at the same tension loads.

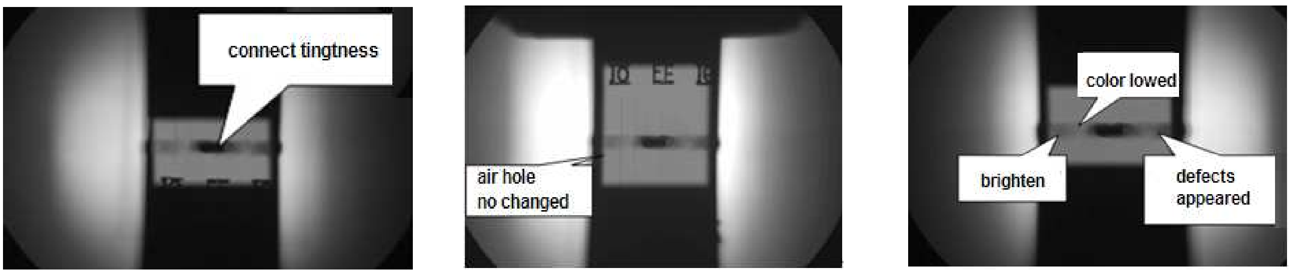
This is because nonpenetration belongs to planar defect, which are very sensitive to the stress concentration. With the increase of the tension load, nonpenetration specimens appear obvious crack. So the stress concentration are released and leakage magnetic field gradient *K* decrease gradually. However, the slag inclusion belongs to volume defects, which is influenced relatively smaller by the tension load. Due to no crack appearance, the stress concentration is accumulated end to end and can't be released. So magnetic field gradient increased obviously.

MMM validity



(a) 0kN (b) 150kN (c) 230kN

Fig.4 X ray examination results of welded joint nonpenetration



(a) 0kN (b) 150kN (c) 230kN

Fig.5 X ray examination results of welded joint slag inclusion

Nonpenetration X-ray testing. The nonpenetration X-ray testing results at the same tension loads are shown in Fig.4. The color of nonpenetration is deep and even in the center of the welded joint at 0kN in Fig.4(a). At 150kN, i.e. yield limit, the welded joint doesn't change obviously and macroscopic defects don't appear in Fig.4(b). When the load reaches to 230kN, i.e. ultimate strength, the obvious crack appears and the color becomes bright in the center of the welded joint in Fig.4(c). This shows that the welded joint defect develops from nonpenetration to macroscopic crack with the increasing of the tension load. The specimens are damaged more and more worse, which is good accordance with MMM testing result.

Slag inclusion X-ray testing. Fig.5(a) is slag inclusion X-ray testing diagram at 0kN. The color of slag section is black, which reflects slag close connected with its surrounding. When loaded reaches to 150KN, the color of slag section doesn't change obviously, which indicates no macro-defect in Fig.5(b). When the load reaches to 230KN, the connection between slag and its surrounding changes from tight to loose, which shows damage appearance in Fig.5(c). It verifies the validity of MMM signal characteristic.

Conclusions

MMM characteristic signals exist in the welded joint defect zones which shows the feasibility of MMM early defect testing. For the nonpenetration specimens, MMM peak amplitude ΔHp and the peak width D adds with the increasing of tensile load, but gradient K varies a little. As for the slag inclusion specimens, MMM peak amplitude ΔHp and gradient K enhances along with tensile load increasing, but the D varies a little. The width D is more sensitive to nonpenetration than slag inclusion, but the gradient K is more sensitive to slag inclusion than nonpenetration.The X-ray testing results at 0kN, 150kN and 230kN tension loads show the validity of MMM signal characteristic. This means the feasibility of the weld qualitative and quantitative evaluation based on MMM method.

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