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TEXTURE FACTOR FOR Θ,ζ,ϒ IDEAL FIBRES BASED NOVEL METHOD OF K_0,K_1,K_2 CONSTANTS EVALUATION OF MAGNETO-CRYSTALLINE ANIOSOTROPY ENERGY DENSITY EQUATION OF ELECTRICAL STEEL

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Abstract

Texture Factor, A* and Magnetic Crystalline Anisotropy Energy Density K1, K2 Constants are important parameters for Electrical Steels. While the former indicates volume density of crystals having preferred Orientation, latter indicates the easy and hard magnetization directions. Evaluation of these parameters for Pure Iron and Electrical Steel enables in reduction of core losses and improving the electrical energy efficiency in Transformers, Rotating Machines. In this research article, an attempt is made to compute Magneto-Crystalline Anisotropy Energy Density for pure iron based on Texture Factor for Ideal fibers.

Keywords: Texture Factor, Magnetic Crystalline Anisotropy Energy Density, Core losses

I. Introduction

The Magneto Crystalline Anisotropy constants K1, K2 values determine the extent to which a material is easily magnetizable. Their value depends on Chemical Composition, Crystal Structure, and Thermo-Mechanical Processing history of the given material. In material science, Texture Factor is an important microstructural parameter which directly determines the anisotropy degree of most physical properties of a polycrystalline material at the macro scale. Its characterization is thus of fundamental and applied importance, and should ideally be performed prior to any physical property measurement or modeling. Neutron diffraction is a tool of choice for characterizing crystallographic textures. The obtained information is representative of a large number of grains, leading to a better accuracy of the statistical description of texture.Texture factor constants K1, K2 , K3values determines the preferred orientations of grains, the Overall Texture Factor is quantitative measurement of texture. The value signifies extent of presence of standard texture viz. Cube Texture (T.F = 22.5), Goss Texture (T.F = 35.6), Gamma Texture (T.F = 38.68) in the given material.

1.1 STANDARD EQUATIONS:

$$E^* = K_0 + K_1 (\sum \alpha_1^2 \alpha_2^2) + K_2 (\prod \alpha_1^2) + K_3 (\sum \alpha_1^2 \alpha_2^2)^2 + K_4 (\sum \alpha_1^2 \alpha_2^2)(\prod \alpha_1^2) + K_5 (\sum \alpha_1^2 \alpha_2^2)^3 + K_6)(\prod \alpha_1^2)^2 ;$$

$$A^* = K_0 + K_1 (\sum \alpha_1^2 \alpha_2^2) + K_2 (\prod \alpha_1^2) + K_3 (\sum \alpha_1^2 \alpha_2^2)^2 + K_4 (\sum \alpha_1^2 \alpha_2^2)(\prod \alpha_1^2) + K_5 (\sum \alpha_1^2 \alpha_2^2)^3 + K_6)(\prod \alpha_1^2)^2 ;$$

$$E^* = 0.355A^* + (0.163 - 0.013A^*)[wt\%Si] - 1.898$$

[uvw]	a	b	c	α_1	α_2	α_3	E
<100>	0	90^0	90^0	1	0	0	K_0
<110>	45^0	45^0	90^0	$1/\sqrt{2}$	$1/\sqrt{2}$	0	$K_0 + K_1/4$
<111>	54.7^0	54.7^0	54.7^0	$1/\sqrt{3}$	$1/\sqrt{3}$	$1/\sqrt{3}$	$K_0 + K_1/3 + K_2/27$

II. ESTIMATION OF MAGNETIC ANISOTROPY CONSTANTS K_2 CONSTANTS EVALUATION FOR ELECTRICAL STEELS

Magneto Crystalline Anisotropy Energy is generally expressed by an expansion into direction cosines α_1, α_2,α_3 of the magnetization with respect to the crystal axes.

$$E^* = K_0 + K_1 (\sum \alpha_1^2 \alpha_2^2) + K_2 (\prod \alpha_1^2) \quad [\ I\ ];$$

$E^* = 0.355A^* + (0.163 - 0.031A^*)[wt\%Si] - 1.898$ from Ref[1]

$E^* = K_0 + K_1 (\sum \alpha^2_1 \alpha^2_2) + K_2 (\prod \alpha^2_1)$ from Ref[1] …..[II]

$K_1 = 4.77 - 0.2125[wt\%Si] - 0.03816[wt\%Al]$ from Ref[1]

We have $A^* = 38.68$ for <111>ϒ texture,

$E^* = 0.355A^* + (0.163 - 0.031A^*)[wt\%Si] - 1.898$

$E^* = 0.355*38.68 + (0.163 - 0.031*38.68)[wt\%Si] - 1.898$

$E^* = 11.8334 - 1.03608[wt\%Si]$

For [111] directions, $\alpha_1 = 1/\sqrt{3}$, $\alpha 2 = 1/\sqrt{3}$, $\alpha_3 = 1/\sqrt{3}$

We have, $11.8334 - 1.03608[wt\%Si]$
$= K_0 + [4.77 - 0.2125[wt\%Si] - 0.03816[wt\%Al]] / 3 + K_2 / 27$

⇨ **$27 * [11.8334 - 1.03608[wt\%Si]$**
$= 9*[4.77 - 0.2125[wt\%Si] - 0.03816[wt\%Al]] + K_2$

⇨ **$K_2 = 276.5718 - 26.06166[wt\%Si] + 0.34344[wt\%Al] - 27 K_0$…..[III]**

⇨ **We have $E^* = [4.77 - 0.2125[wt\%Si] - 0.03816[wt\%Al]] (\sum \alpha^2_1 \alpha^2_2)$**
$+ [276.5718 - 26.06166[wt\%Si] + 0.34344[wt\%Al]] (\prod \alpha^2_1)$

⇨ **$E^* = K_0 + [4.77 - 0.2125[wt\%Si] - 0.03816[wt\%Al] (\sum \alpha^2_1 \alpha^2_2)$**
$+ [276.5718 - 26.06166[wt\%Si] + 0.34344[wt\%Al]] (\prod \alpha^2_1)$ From …. **[I]**

We have, <110> directions, $A^* = 35.6$
⇨ **$E^* = 0.355*35.6 + (0.163 - 0.031*35.6)[wt\%Si] - 1.898$**
⇨ **$E^* = 10.74 - 0.9406[wt\%Si]$**

For <110> directions, $\alpha_1 = 1/\sqrt{2}$, $\alpha 2 = 1/\sqrt{2}$, $\alpha_3 = 0$

$10.74 - 0.9406[wt\%Si] = K_0 +$
$[4.77 - 0.2125[wt\%Si] - 0.03816[wt\%Al]] / 4$

⇨ **$K_0 = 9.5475 - 0.887475[wt\%Si] - 0.00954[wt\%Al]$ ……..[IV]**

We have from …..[III],
$K_2 = 276.5718 - 26.06166[wt\%Si] + 0.34344[wt\%Al] - 27 K_0$

$K_2 = 276.5718 - 26.06166[wt\%Si] + 0.34344[wt\%Al]$
$-27[9.5475 - 0.887475[wt\%Si] - 0.00954[wt\%Al]]$

$K_2 = 18.7893 - 2.099835[wt\%Si] + 0.60102[wt\%Al]$ …..[V]

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Substuting K_0, K_1, K_2 Values in

$E^* = K_0 + K_1 (\sum \alpha^2_1 \alpha^2_2) + K_2 (\prod \alpha^2_1)$ [I];

We have , $E^* = [9.5475 - 0.887475[wt\%Si] - 0.00954[wt\%Al]] + [4.77 - 0.2125[wt\%Si] - 0.03816[wt\%Al](\sum \alpha^2_1 \alpha^2_2) + [18.7893 - 2.099835[wt\%Si] + 0.60102[wt\%Al]](\prod \alpha^2_1)$ …..[VI]

CRYSTALLOGRAPHIC DIRECTION	MAGNETO-CRYSTALLINE ANISOTROPY ENERGY DENSITY
[100] $\alpha_1 = 1, \alpha_2 = 0, \alpha_3 = 0$	$E^*_{[100]}$ = 9.5475 -0.887475[wt%Si] - 0.00954[wt%Al]
[110] $\alpha_1 = 1/\sqrt{2}, \alpha_2 = 1/\sqrt{2}, \alpha_3 = 0$	$E^*_{[110]}$ = 10.74 -0.9406[wt%Si] - 0.01908[wt%Al]
[111] $\alpha_1 = 1/\sqrt{3}, \alpha_2 = 1/\sqrt{3}, \alpha_3 = 1/\sqrt{3}$	$E^*_{[111]}$ = 11.8334 -1.03608 [wt%Si]

FOUR ELECTRICAL STEELS, WITH COMPOSITIONS OF VARIOUS ELEMENTS AND BALANCE IS IRON

S.NO	C	Mn	Si	Al	P	S	N	O
A1.	0.002	0.33	0.51	0.13	0.15	0.001	0.005	nil
A2.	0.002	0.34	1.38	0.11	0.019	0.001	0.009	nil
A3.	0.003	0.3	2.8	0.52	0.01	0.01	0.0008	0.0021
A4.	0.004	0.4	3.2	0.58	0.0095	0.0027	0.0034	0.0037

CRYSTALLOGRAPHIC DIRECTION,E*	A1.	A2.	A3.	A4.
<100> $\alpha_1 = 1, \alpha_2 = 0, \alpha_3 = 0$ **$E^*_{[100]}$ = 9.5475 - 0.887475[wt%Si] -0.00954[wt%Al]**	Si=0.51 Al=0.13 9.0936	Si=1.38 Al=0.11 8.3217	Si = 2.8 Al=0.52 7.0576	Si=3.2 Al=0.58 6.7020
<110> $\alpha_1 = 1/\sqrt{2}, \alpha_2 = 1/\sqrt{2}, \alpha_3 = 0$ **$E^*_{[110]}$ = 10.74 -0.9406[wt%Si] -0.01908[wt%Al]**	10.2578	9.4398	8.0963	7.7190
<111> $\alpha_1 = 1/\sqrt{3}, \alpha_2 = 1/\sqrt{3}, \alpha_3 = 1/\sqrt{3}$ **$E^*_{[111]}$ = 11.8334 -1.03608 [wt%Si]**	11.3049	10.4036	8.932	8.517

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2.1 Discussion

Magnetic Anisotropic Density Decreases with increase in Silicon content,its least for <100> directions than <110>,<111> directions respectively. This indicates Magnetizing Electrical Steel along <100> directions is easy when compared to <110>,<111> directions. **From Ref[1]**,The <100>//ND fibre accounts for the lowest anisotropy energy since the flux lines, distributed homogenously in a plane of the rotating laminated sheet, have an easiest magnetization direction with the in-plane rotated cube texture components. On the contrary, the ϒ and the <011>//ND fiber orientations have relatively high anisotropy energy and as such, the occurrence of these components in electrical steels is undesirable.

III. ESTIMATION OF TEXTURE FACTOR CONSTANTS EVALUATION FOR ELECTRICAL STEELS

$E^* = 0.355A^* + (0.163 - 0.031A^*)[wt\%Si] - 1.898$ from Ref[1]

⇨ **$E^* = [0.355 - 0.031[wt\%Si]\ A^* + (0.163)[wt\%Si] - 1.898$**

⇨ **$E^* = [9.5475 - 0.887475[wt\%Si] - 0.00954[wt\%Al]] + [4.77 - 0.2125[wt\%Si] - 0.03816[wt\%Al](\sum\alpha^2_1\alpha^2_2) + [18.7893 - 2.099835[wt\%Si] + 0.60102[wt\%Al]](\prod\alpha^2_1)$**

⇨ **$[0.355 - 0.031[wt\%Si]\ A^* + (0.163)[wt\%Si] - 1.898$**

⇨ **$= [9.5475 - 0.887475[wt\%Si] - 0.00954[wt\%Al]] + [4.77 - 0.2125[wt\%Si] - 0.03816[wt\%Al](\sum\alpha^2_1\alpha^2_2) + [18.7893 - 2.099835[wt\%Si] + 0.60102[wt\%Al]](\prod\alpha^2_1)$**

⇨ **$[0.355 - 0.031[wt\%Si]\ A^* =$**

⇨ **$[9.5475 + 1.898 - 0.887475[wt\%Si] - (0.163)[wt\%Si] - 0.00954[wt\%Al]] + [4.77 - 0.2125[wt\%Si] - 0.03816[wt\%Al](\sum\alpha^2_1\alpha^2_2) + [18.7893 - 2.099835[wt\%Si] + 0.60102[wt\%Al]](\prod\alpha^2_1)$**

⇨ **$[0.355 - 0.031[wt\%Si]\ A^* =$**

$[11.4455 - 1.050475[wt\%Si] - 0.00954[wt\%Al]] + [4.77 - 0.2125[wt\%Si] - 0.03816[wt\%Al](\sum\alpha^2_1\alpha^2_2) + [18.7893 - 2.099835[wt\%Si] + 0.60102[wt\%Al]](\prod\alpha^2_1)$

⇨ **We have, $A^* = K_0 + K_1(\sum\alpha^2_1\alpha^2_2) + K_2(\prod\alpha^2_1)$**

$K_0 = \dfrac{[11.4455 - 1.050475[wt\%Si] - 0.00954[wt\%Al]]}{[0.355 - 0.031[wt\%Si]}$

$K_1 = \dfrac{[4.77 - 0.2125[wt\%Si] - 0.03816[wt\%Al]}{[0.355 - 0.031[wt\%Si]}$

$K_2 = \dfrac{[18.7893 - 2.099835[wt\%Si] + 0.60102[wt\%Al]}{[0.355 - 0.031[wt\%Si]}$

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S.NO	C	Mn	Si	Al	P	S	N	O
A1.	0.002	0.33	0.51	0.13	0.15	0.001	0.005	nil
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A3.	0.003	0.3	2.8	0.52	0.01	0.01	0.0008	0.0021
A4.	0.004	0.4	3.2	0.58	0.0095	0.0027	0.0034	0.0037

S.NO	A1	A2	A3	A4
K_0	32.16	32.012	31.6898	31.5811
K_1	13.7287	14.325	15.49275	15.9025
K_2	52.4676	51.1102	49.30012	48.5473

⇨ **We have, $A^* = K_0 + K_1 (\sum\alpha^2_1 \alpha^2_2) + K_2 (\prod\alpha^2_1)$**

For A1, $A^* = 32.16+13.7287(\sum\alpha^2_1 \alpha^2_2)+ 52.4676(\prod\alpha^2_1)$
For A2, $A^* = 32.012+14.325(\sum\alpha^2_1 \alpha^2_2)+ 51.1102(\prod\alpha^2_1)$
For A3, $A^* = 31.6898+ 15.49275(\sum\alpha^2_1 \alpha^2_2)+ 49.3001 (\prod\alpha^2_1)$
For A4, $A^* = 31.5811+ 15.9025 (\sum\alpha^2_1 \alpha^2_2)+ 48.5473 (\prod\alpha^2_1)$

FOR <110> Directions, A*=35.6

FOR <110> Directions, A1 => A*= 35.592175 ≈35.6
FOR <110> Directions, A2 => A*= 35.59325 ≈35.6
FOR <110> Directions, A3 => A*= 35.5629875 ≈35.6
FOR <110> Directions, A4 => A*= 35.556725 ≈35.6

FOR <111> Directions, A*=38.68

FOR <111> Directions, A1 => A*= 38.67947 ≈38.68
FOR <111> Directions, A2 => A*= 38.67997 ≈38.68
FOR <111> Directions, A3 => A*= 38.67997 ≈38.68
FOR <111> Directions, A4 => A*= 38.67998 ≈38.68

5. CONCLUSIONS:

Magneto-Crystalline Anisotropy Energy Density value is least for [100] directions, and higher for [110] & [111] directions. Therefore [100] directions are easy directions of magnetization for pure iron and [111] hardest direction for magnetization of pure iron, [110] direction is harder direction for magnetization of pure iron. Texture Factor Equation results are consistent with the standard results and conforms to the value of ideal fibres.

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